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AD 522104

FINAL REPORT
ACOUSTIC TEST ARRAY (U)

CONTRACT N00014-72-C-0465

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13. ABSTRACT

This report covers a design analysis of a series of vertically strung hydrophones connected together by a horizontal signal cable and terminating in an SDC cable currently available at a test site 45 miles SE of Bermuda. The report treats the acoustic signal electronics, deployment and shore command requirements to obtain a successful system implantment and operation for a low frequency propagation study in support of LRAPP and a Suspended Array.

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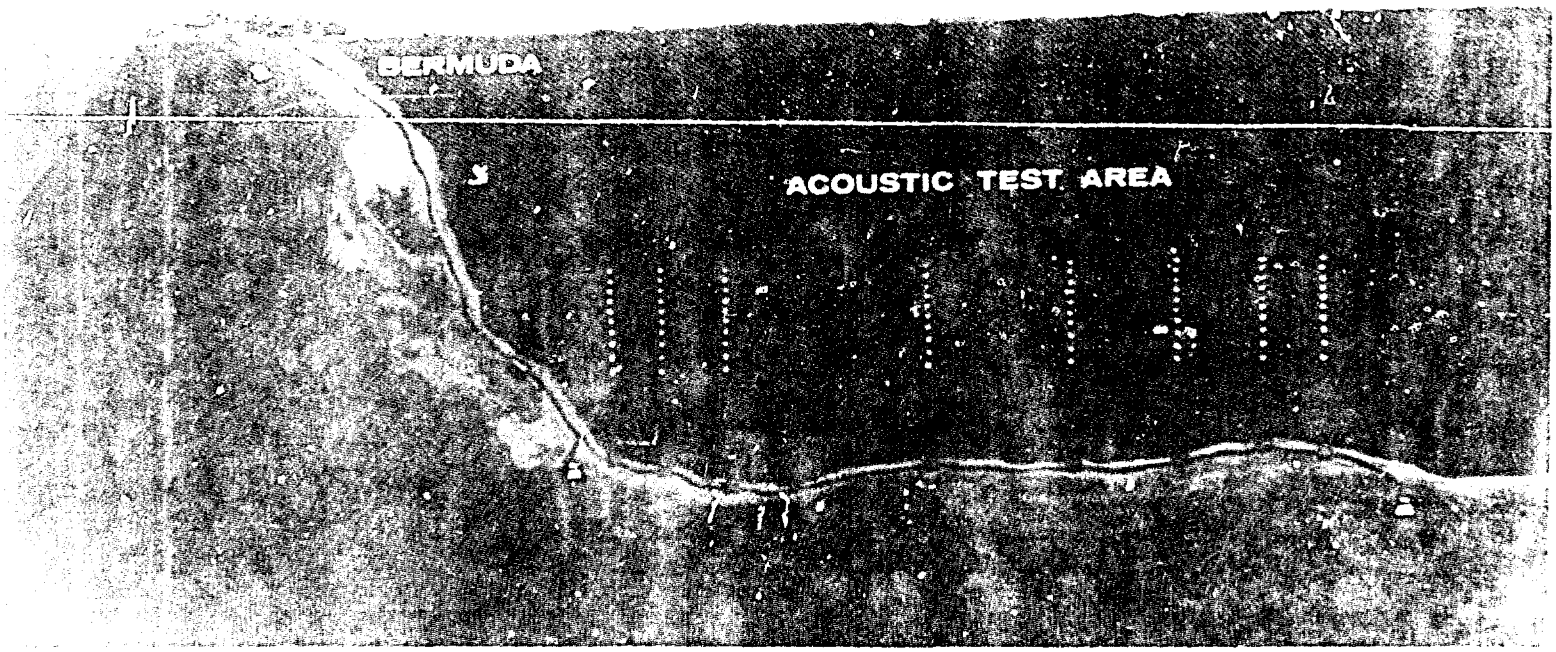

(U) 1.0 INTRODUCTION

(C) Raytheon's Submarine Signal Division and the Vitro Laboratories Division of Automated Industries, having successfully teamed for the past 18 months in the development of the Kilroy concept, have again pooled their expertise and resources to develop an Acoustic Test Array. This array is intended for deep water propagation studies in the frequency range of 5 to 160 Hz and, in particular, to gather data for the following:

- Low frequency background noise
- Low frequency signals
- Seasonal variations in propagation characteristics.

(C) It is further intended that this array be deployed in water depths to 20,000 feet, operate for one year with 90% confidence and be available for deployment within nine months of date of contract. The first installation specified by the Navy will occur 45 miles southeast of Bermuda, where the water depth is 14,000 feet and where an underwater coaxial cable has been previously installed for data transmission to shore laboratories.

(U) This technical report addresses three configurations of the Acoustic Test Array, two of which bound the scope of the study, and a third which is the recommended configuration. The characteristics, advantages and disadvantages of each, including design and deployment details, are described. This report also presents a detailed program plan for the successful development of the array and, in a separate enclosure, a pricing schedule for all three options.

(U) The three arrays to be considered are:

- A Basic Array, of four vertical lines spaced over a horizontal distance of 5250 feet; each line contains five hydrophones and extends 1000 feet above the ocean bottom.
- A Recommended Array, of four vertical lines spaced over 5250 feet horizontally; each vertical line contains ten hydrophones and extends 2000 feet above bottom.
- An Expanded Array, of eight vertical lines spaced over a horizontal distance of 21,750 feet; each vertical line contains ten hydrophones and extends 2000 feet above bottom.

(U) These configurations were selected from a variety of options. Each array, in its own right, has the flexibility to offer a wide range of experimental capability. All the arrays are characterized by their simplicity, usefulness, modularity and ease of installation. Each array is described in detail in following sections of this report.

(U) 1.1 Background

(U) Under Contract N00014-72-C-0465, Submarine Signal Division (SSD) and Vitro conducted a feasibility study of an Acoustic Test Array. The purpose of the study was to develop the technical constraints, and to provide system trade-offs and options for an operational system. The systems described herein, which reflect the results of this study, are an extension of an unsolicited technical proposal submitted by SSD and Vitro in March 1972.

(U) 1.2 System Description

(U) The proposed test array configurations are based on inputs from data supplied by the Office of Naval Research (NRL). Each array is a cable-connected series of vertical strings of hydrophones suitable for conducting acoustic propagation experiments at low frequencies. The hydrophone depths have been carefully selected in order to permit sampling of critical portions of the water column. The hydrophones in each vertical string are suspended above the ocean floor by a float and a multiconductor vertical array cable. Each vertical array cable is anchored by a substation with the vertical array float and hydrophones protected and housed in the substation during system implant. The horizontal spacing of the substations and, therefore, the vertical hydrophone array, is maintained by a tensioned interstation cable.

(U) The three system options formulated are designated the Basic, the Recommended, and the Expanded Array. They are described and illustrated on the following pages.

(C) The Basic Acoustic Test Array contains four vertical lines of five hydrophones each with the vertical lines spaced 250 feet, 4,000 feet, and 1,000 feet apart. The four-station array configuration is shown in Figure 1-1.

(C)

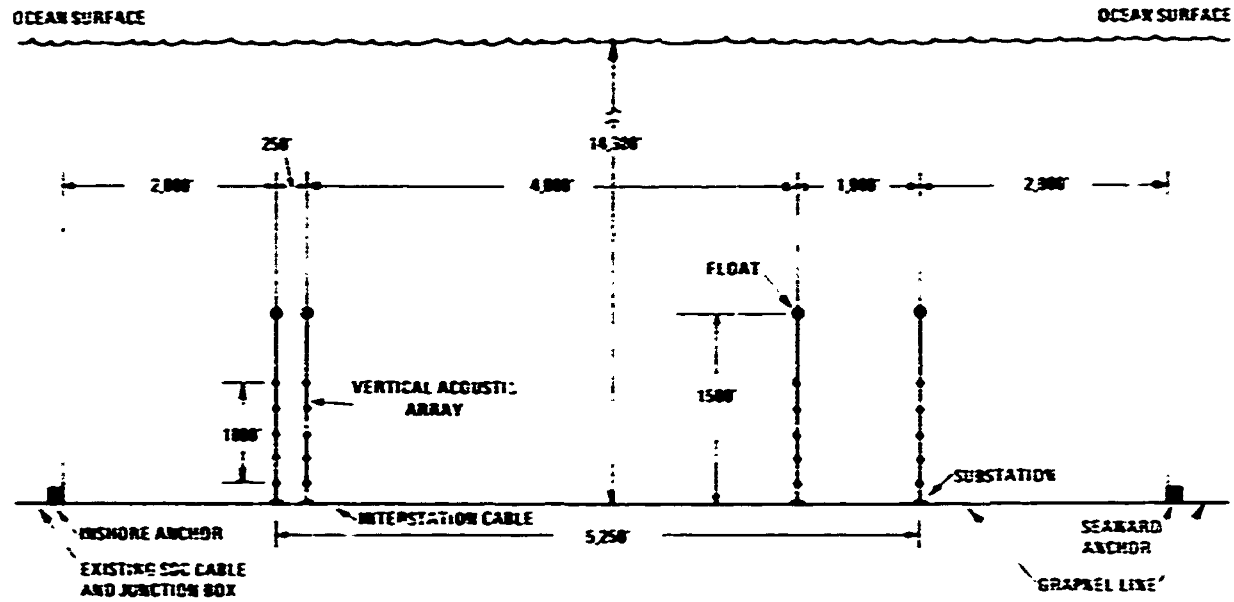

Figure 1-1. Basic Acoustic Test Array

(C) The Recommended Array has the same horizontal spacing as the Basic array, but contains ten hydrophones per vertical line. This array is shown in Figure 1-2.

(C)

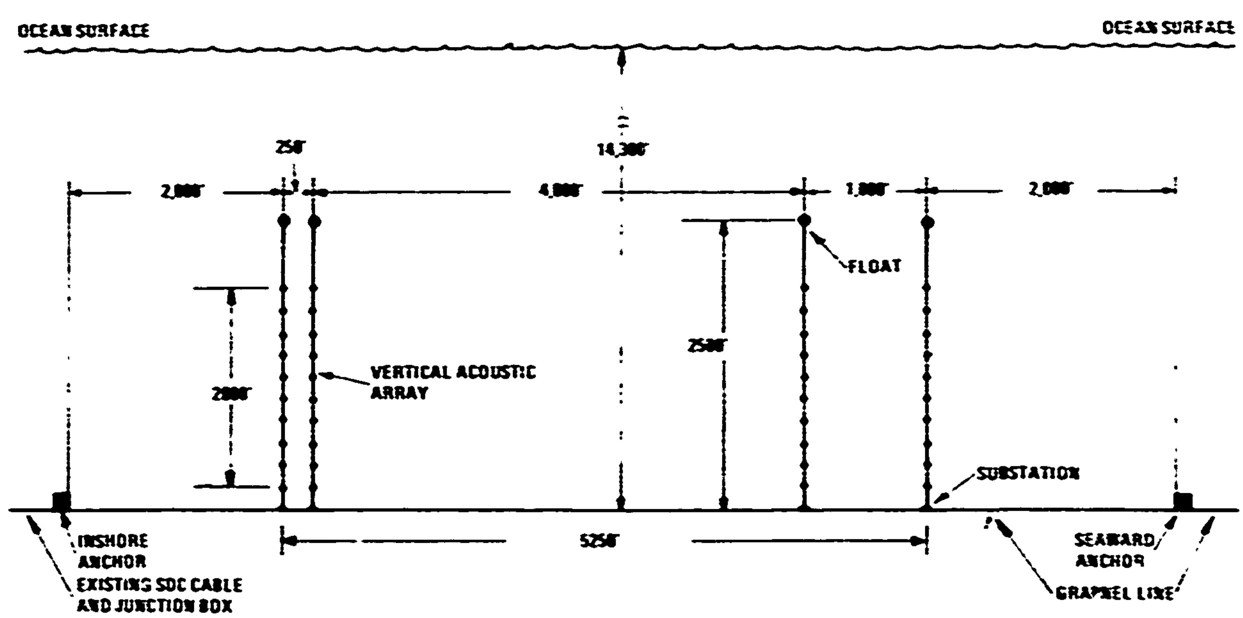

Figure 1-2. Recommended Acoustic Test Array

(C) The Expanded Acoustic Test Array contains eight vertical arrays of ten hydrophones each and the horizontal aperture of the array has been increased to 21,750 feet. The spacings of the adjacent substations form a nearly symmetric geometric progression; the spacings were selected to provide sufficient redundancy, especially for the longer horizontal array spacings. The configuration of the eight-substation array is shown in Figure 1-3.

(C)

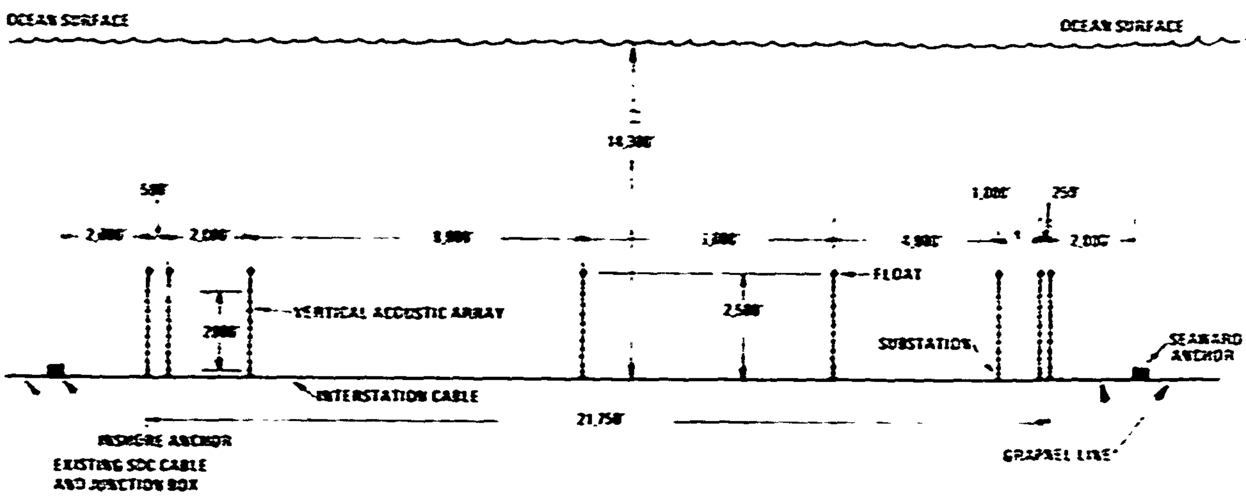

Figure 1-3. Expanded Acoustic Test Array

(C) Sensor data from individual hydrophones, a measure of array tilt, and substation depth will be collected at the substation, converted to digital format and transmitted, on command, on the single conductor coaxial interstation cable. The interstation cable is a coaxial-type signal transmission cable with two layers of steel armor and an outer jacket to provide environmental protection. The data transmission path is from the seaward substation to subsequent substations and then over the 45 miles of SDC transmission cable to the shore station at Tudor Hill Laboratory in Bermuda.

(U) In any Acoustic Test Array configuration, the sensor data from any arbitrary ten sensors will be made available simultaneously at the shore station command console. Power to the system, as well as command and calibration signals, will be supplied from this console. The command signals include turning equipment on and off, selecting hydrophones to be monitored, inserting calibration signals, changing the gain of individual hydrophones, and adjusting the height of the hydrophones above bottom.

(U) The adjustable height feature, a recommendation for any system, allows for equalizing the depth of all hydrophones in a horizontal layer by shore command after implantment.

(U) 2.0 PROBLEM STATEMENT

(C) The problem statement given by ONR for the Acoustic Test Array is:

- A system that will return to a shore station unprocessed low frequency ambient noise and signal data in support of LRAPP, and other programs such as the Suspended Array.

(U) The Acoustic Test Array is intended as a basic instrument for acquiring unprocessed low frequency acoustic data in a deep ocean environment, transferring the data via cable to a shore station for processing and recording, and maintaining its operation and calibration by means of auxilliary shore station equipment. Typical data to be received include noise, broadband signals such as bomb shots, and narrowband signals such as pings (Appendix B). The processing and recording of the data is beyond the scope of the function of the acoustic test array, by definition. However, the data must be compatible with a reasonably wide variety of prospective measurement applications. Some of these applications involve coherency of signals and noises as a function of hydrophone spacing in horizontal and vertical directions, estimates of directions of arrival of acoustic energy, study of seasonal effects on sound propagation, location of sound ray caustics, and testing of wave theory versus ray theory predictions as a function of frequency. While necessarily incomplete, the above statement suggests a set of specifications for the development and deployment of the acoustic test array. The minimum specifications for a known test site near Bermuda are outlined in Table 2-1, with comments where additional constraints have been applied.

(U) While there is no upper limit to what may be desirable for the greatest versatility of application, some arbitrary limits have been set so that a practical system can be deployed in a reasonable time period and at a reasonable cost with high reliability.

Table 2-1. Minimum System Specifications for the Acoustic Test Array

(C)

1. In-Shore Deployment Termination at Bermuda Test Site	Existing SDC cable
2. Bottom Depth at Bermuda Test Site	Approximately 14,300 feet
3. Horizontal Direction of Deployment	Along nearly constant bottom depth contour
4. Minimum Horizontal Length of Array	5000 feet
5. Primary Depths of Hydrophones	Near critical depth*
6. Minimum Vertical Height above Bottom of Uppermost Hydrophones	800 feet
7. Uniformity of Depths of Each Horizontal Layer of Hydrophones (depth is measured from the sea surface)	±50 feet
8. Minimum Number of Hydrophones Accessible Through Operating Life	Three horizontal by three vertical, or equivalent (requires more than the apparent minimum of nine)
9. Minimum Dynamic Range (allows step gain control on command)	60 decibels
10. Maximum Data Transmission Rate (based on loss in existing SDC cable)	100 kilobits/second
11. Minimum Operating Frequency Band	5 to 160 hertz
12. Minimum Operating Life with at Least 90% Confidence	One year

*Critical depth is defined as that depth, below the SOFAR channel axis, at which the sound speed is equal to the greatest sound speed in the surface channel region.

(U) 3.0 OVERALL DESCRIPTION

(U) The section emphasizes a Recommended System for the Acoustic Test Array. The Recommended System contains four vertical cable strings, each with ten hydrophones, a pair of tilt sensors and a depth sensor. The four strings provide a maximum horizontal base line of 5250 feet, and the nominal heights of the hydrophones of the hydrophones on a string, above bottom, vary from 200 feet to 2000 feet. Adjustments of the nominal heights above bottom are provided to set the relative hydrophone depth among strings to within ±50 feet. Data from up to ten arbitrarily selected sensors, i.e., hydrophone, tilt, or depth, may be commanded to be A/D converted to 12-bit words, sampled at 600 Hz, and transmitted to a shore terminus at 93.600 kHz via interstation cabling and a currently existing SDC cable 45 miles long. Deployment of the Recommended System is estimated to take about 15 hours on station from a single ship following the development program.

(C) Prescribed bounds were established for system configurations in this study. The lower boundary of these configurations is called the Basic System and the upper boundary the Expanded System. The Basic, Recommended and Expanded Systems described meet the development requirements presented to us by ONR for:

- A system that will return to a shore station unprocessed low frequency ambient noise and signal data in support of LRAPP, and other programs such as the Suspended Array.

(U) The system configurations were synthesized by SSD and Vitro using many ideas suggested by personnel at the Office of Naval Research (ONR), Naval Underwater Systems Center New London (NUSC/NL), Woods Hole Oceanographic Institute (WHOI), Tracor-MAS, and Rochester Corp., which are gratefully acknowledged. Our goal has been to present systems that fulfill the requirements set for us, and be:

- Simple
- Modular
- Reliable
- Useful.

(U) The reasons for our preference of the Recommended System become more evident from discussion of the trade-offs that are examined in this section. Program risk and cost are among the factors considered in selecting an effective system.

(U) 3.1 Choice of Systems

(U) During June through August, 1972, several meetings were held with Dr. R. Gaul of the Naval Research Laboratory; Mr. R.W. Hasse of the Navy Underwater Systems Center, New London Laboratory; and internally among the Raytheon/Vitro contract team members. Analysis of the reference reports and other data obtained partially as a result of the above meetings has led to an updating of the acoustic test array configuration, superseding that proposed initially in Reference 1*. The fundamental requirement for the acoustic test array is that it be designed for experiments at low frequencies when deployed near Bermuda. Low complexity, high flexibility of operation, and high reliability are primary design features required.

(U) A priority for selecting hydrophone depths was recommended by Hasse as: (1) the critical depth (or slightly below it), (2) the SOFAR channel depth (i.e., minimum sound speed), (3) near the bottom, and (4) the region above the critical depth but below the SOFAR channel depth. The critical depth is defined as that depth below the SOFAR channel axis at which the sound speed is equal to the greatest average sound speed in the depth region within five hundred meters of the surface. In other words, a horizontal ray at the critical depth would also be horizontal, in accordance with Snell's Law, at the near-surface depth at which the sound speed is greatest. The current design presented below emphasizes the first priority item and includes some items of lower priority primarily as a by-product.

(C) Based on the data in Reference 2, the average sound speed in the region from zero to 500 meter depth has a greatest value that varies from 1523.1 m/s to 1541.8 m/s as a function of the month of the year. Also, the sound speed data at depths below 2000 meters may be closely represented by $1498.2 + 0.014\,(d-2000)$ m/s, independent of the time of year. Estimates of the minimum depths for surface reaching rays as a function of the sound ray angle above the

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*References are listed in Appendix I.

(C)

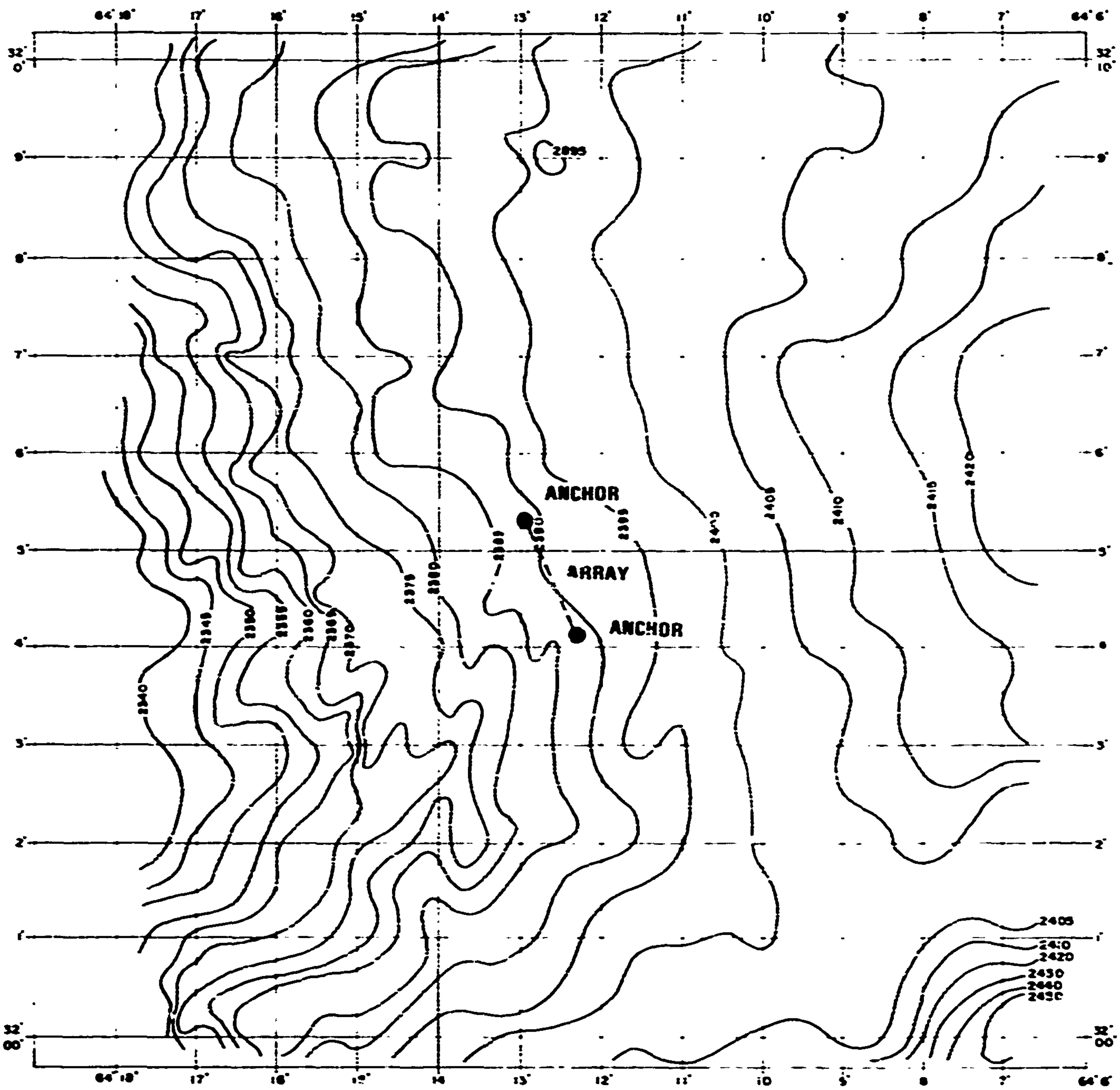


Figure 3-1. Acoustic Test Array Site

Table 3-1. Minimum Depths (Below SOFAR Channel) for Surface Reaching Rays

(U)

Month of Year	Greatest Average Sound Speed in Surface Channel $0 < d < 500m$ (m/s)	Minimum Depths* for Sound Ray Angles Above Horizontal (m)					
		0°	+3°	+6°	+9°	+12°	+15°
January	1525.6	3960	3810	3350	2610	~1560	——
February	1523.8	3830	3680	3230	2480	Near SOFAR CHANNEL AXIS	——
March	1523.4	3800	3650	3200	2450		——
April	1523.1	3780	3630	3150	2430		——
May	1526.9	4050	3900	3450	2700	~1650	——
June	1534.8	4610	4460	4010	3260	2210	——
July	1539.1	4920	4770	4320	3570	2520	——
August	1541.8	5110	4960	4510	3760	2710	Near SOFAR CHANNEL AXIS
September	1541.3	5080	4930	4480	3730	2680	
October	1538.4	4870	4720	4270	3520	2470	——
November	1533.4	4510	4360	3910	3160	2110	——
December	1528.9	4190	4040	3590	2840	~1790	——

* All depths are listed relative to the sea surface. Critical depths are those listed in the 0 column.

Table 3-2. Criteria for Selecting Hydrophone Depths and Horizontal Spacings

(U)

Criterion	Comment
Number of hydrophones per vertical string shall be equal.	See Appendix A for more detail.
Surface reaching sound rays from at least three hydrophones other than the deepest hydrophone, shall have a negative (downward) angle during at least a few months of the year.	First priority item.
Set of hydrophone depths in each vertical string shall be nearly equal.	Minimum requirement, ±50 feet (±15 m)
Height above bottom of deepest hydrophone shall adjustable between 12 m (40 ft.) and 60 m (200 ft.) to permit stabilizing depths of each string.	Third priority item.
Minimum depth of uppermost component (float) shall be 3000 m (10,000 ft.).	Effects of water current favor as deep deployment as practical. Consideration of suspending a SOFAR channel hydrophone above the float has not been included in the scope of proposed effort.
Minimum depth of uppermost hydrophone shall be 3150 m (10,500 ft.).	See above comment.
Minimum separation of any hydrophone from any other hydrophone or float shall be 30 m (100 ft.).	See Appendix A for more detail.
Modular design procedures shall be preferred.	Average vertical spacings between hydrophones are limited to a maximum of 75 m.
Horizontal separations of adjacent hydrophone strings shall be geometrically related.	Exception is permissible for one separation to fulfill other criteria.
Minimum horizontal separation of outermost strings shall be 5000 ft. (~1500 m)	Allows no margin below recommended minimum value.
Maximum horizontal separation of outermost strings shall be 22,000 ft. (~6600 m).	Allows 10% margin over recommended maximum value.
At least two spacings, each greater than 75% of the outermost design spacing, shall be available.	Must permit loss of any one string, even for minimum system; also must permit loss of one string out of each consecutive set of three for maximum system. See Section 6.1.
At least one spacing less than 20% of the outermost design spacing shall be available.	See above comment. Similar reliability must be planned for any intermediate system configuration. See Section 6.1.

Table 3-3. Preferred (Float) and Hydrophone Depths (Meters)

(U)

Bottom Depth, D (m)	Five hydrophones per string. H H H H H	Ten hydrophones per string. H H H H H H H H H H	Monthly Variation of Average Critical Depth.
D = 4370 (nominal)		(3630)	
Deepest hydrophone height above bottom, adjustable during deployment, to be between 12 and 60 m to stabilize depths of each string		3780	March — April
		3840	February
	(3930)	3900	
		3960	January
		4020	May
	4080	4080	
	4140	4140	
	4200	4200	December
	4260	4260	
	4320	4320	November
			June
			October
			July
			September
			August

Table 3-4. Test Array Configuration Matrix

(U)

Horizontal Spacings of Hydrophone Strings (ft)	Five hydrophones per string. H H H H H	Ten hydrophones per string. H H H H H H H H H H
250; 4000; 1000 (four strings, total length = 5,250)	Basic Configuration (Similar to Reference 1)*	Recommended Configuration (See Discussion and Appendix A).
500; 2000; 8000; 6000; 4000; 1000; 250 (eight strings, total length = 21,750)		Expanded Configuration (In This Study, Maximum Expansion of Scope).

*Reference configuration had 5000, 500, 50 foot spacings. (Four strings, total length = 5550.)

(C) horizontal plane were made and the results are given in Table 3-1. The standard deviations of the data affect the tabulated values by up to about 300 m, and this magnitude tends to increase for extrapolations above 2000-meter depth and below 5000-meter depth. This was satisfactorily checked against another plot made available to us. The sea surface is the zero reference for all depths; the term "height above bottom" is used when applicable.

(C) The site where the acoustic test array is to be deployed has been given as southeast of Bermuda, approximately 32°04'N, 64°12'W (Figure 3-1). The bottom topography along the planned horizontal direction of the array is a nearly isodepth contour with bottom depth of 2390 ±5 fathoms, or approximately 4370 ±10 meters. Limited data from three current meters in the spring of 1970 (Reference 3) indicated that peak and average flow rates at a depth of about 1000 m were about twice as great as at 2000 m or deeper; i.e., 0.20 and 0.064 m/s versus 0.10 and 0.03 to 0.04 m/s.

(U) The criteria used for selecting the hydrophone depths are listed in Table 3-2 with appropriate comment and discussed in more detail in Appendix A. The selections of depths for vertical strings of five to ten hydrophones are given for the uniform spacing case as an example in Table 3-3. Indication of the critical depth is given at the right side of the table; from mid-January thru mid-May most hydrophones are below the critical depth, while from mid-June thru mid-November all hydrophones are necessarily above the critical depth, which has a calculated value below the depth of the bottom. The critical depth makes one upward and one downward transit of the array during the colder half of the year. An average vertical depth separation of 60 m (200 feet) between hydrophones is indicated with the float 150 m (500 feet) above the uppermost hydrophone; however, the hardware design can accomodate almost any reasonable modification from this vertical configuration as long as the height above bottom of the float is not increased significantly. (See Appendix A.)

(U) The criteria used for selecting the horizontal spacings between vertical strings of hydrophones are listed near the end of Table 3-2. Total horizontal spacing was recommended to be between 5000 and 20,000 feet for all cases. A 10% margin above the higher value was taken for design convenience in selecting a set of geometrically related spacings of hydrophone strings. Reliability considerations, discussed in Section 6.0, suggested the use of a maximum horizontal spacing near the center of the set of hydrophone strings, geometrically

(U) decreasing toward one end, and allowance for one arbitrarily selected spacing prior to a geometrically decreasing spacing toward each end.

(U) Table 3-4 shows the test array configuration matrix limiting conditions for arrays of four to eight strings of hydrophones, the minimum containing twenty hydrophones (four strings of five hydrophones) and the maximum eighty (eight strings of ten). Many intermediate options exist in the twenty-one to seventy-nine hydrophone categories. Two other limiting conditions are among them, one consisting of four strings of ten hydrophones and the other eight strings of five hydrophones, each of which contains forty hydrophones. For reasons outlined in Appendix A, and because a string of ten hydrophones is the design more readily expandable to the largest configuration considered in the study, the four strings of ten hydrophones are the recommended system.

(U) 3.2 Functional Description

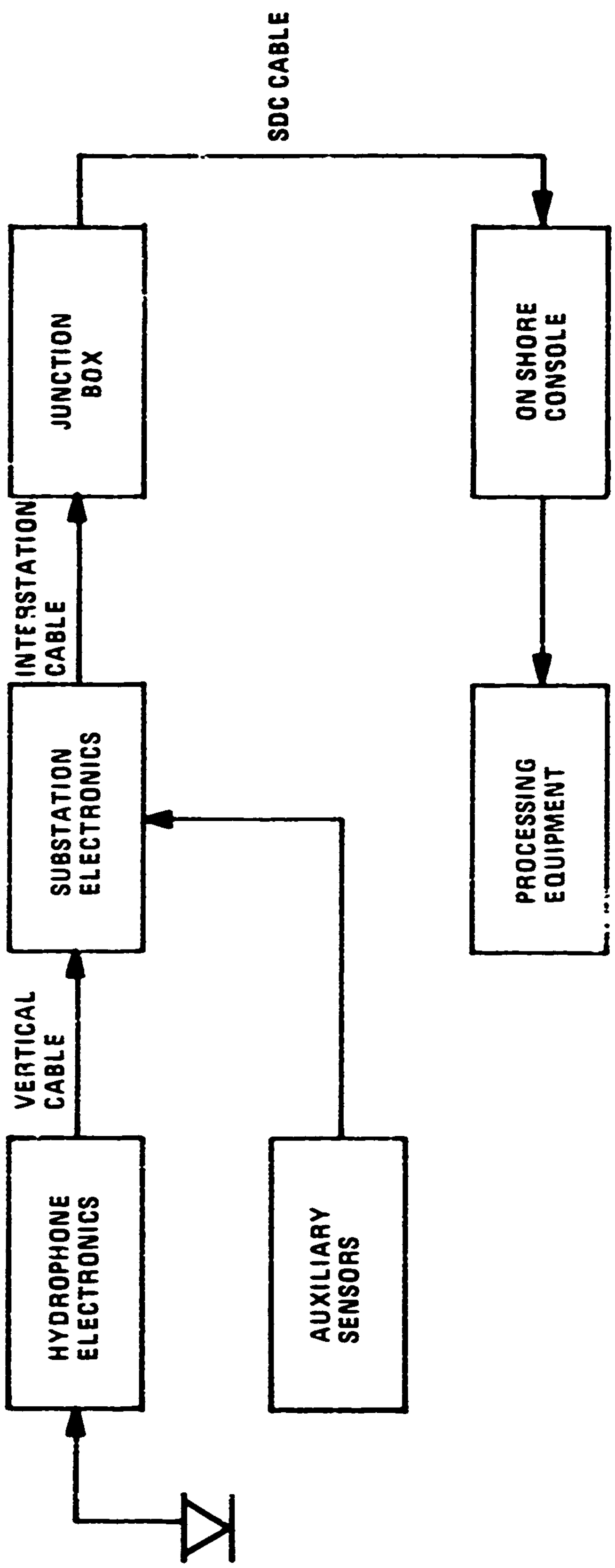
(C) Shown in Figure 3-2 is a general functional block diagram of the ATA System. The system consists of from four to eight vertical strings of hydrophones, each vertical string containing from five to ten hydrophones. The system, as presently designed, is modular in concept and any configuration within the aforementioned limits is feasible. The following is a discussion of each of the blocks in Figure 3-2.

(C) Associated with each hydrophone is a preamplifier which is physically located within the hydrophone cavity. As a bare minimum, this preamplifier should:

- Cover the five-octave frequency band from 5 to 160 Hz
- Have self-noise at least 10 dB less than that given by Wenz for deep water traffic noise (Reference 4)
- Provide a minimum of 60 dB dynamic range
- Have the capability of being calibrated from shore
- Have four gain settings selectable from shore.

Note

An electronic short or seawater short within the hydrophone cavity shall result in the loss of that one hydrophone only and shall not affect the rest of the substation.



(U)

Figure 3-2. ATA Functional Block Diagram

(C) The preamplifier drives an analog signal down the vertical cable to the substation where the signal is A/D converted and on command is multiplexed onto the interstation cable.

(U) The substation consists of three cavities which are both mechanically and electrically independent of each other for reliability purposes. Two of the cavities are identical and each contains presampling filters and an A/D converter. The third cavity contains redundant repeaters which serve to insert data on the line and to retransmit data from other substations. The two identical cavities each independently supply power to, and process data from, one half of the hydrophones in the vertical cable string. Consequently, the total loss of one of these two cavities due to electronic failure or seawater short will allow uninterrupted operation of the other half of the substation.

(U) The substation also transmits the data from tilt and depth sensors. The tilt sensor, which is located on the vertical cable, measures the tilt of the vertical cable due to water currents while the depth sensor, which is located at the substation, measures the depth of the substation to aid in deployment. Insofar as signal handling is concerned, the tilt and depth sensors are treated identically to hydrophones.

(C) The recommended electrical design characteristics of the substation are as follows:

a) The repeater shall be capable of synchronizing to, and retransmitting data from, more seaward stations

b) The repeater shall be capable of inserting data on the line from those sensors required by shore commands

c) The repeater shall be capable of being a slave station (simple repeater) or a master station (timing generator) as commanded from shore

d) The system shall process a minimum five-octave frequency band of 5 to 160 Hz

e) Aliasing due to sampling shall be more than 40 dB down in the band DC to 200 Hz

f) All data shall be quantized to 12 bits.

(U) The basic operation of the system involves one station (the most seaward) acting as a master station and generating a timing code to which all other station synchronize. Any station, however, must have the ability to be a master station in the event that the most seaward station fails. The slave stations synchronize to the data on the line, reshape the data pulses, insert new data and, then, retransmit the data to the next shoreward station.

(U)

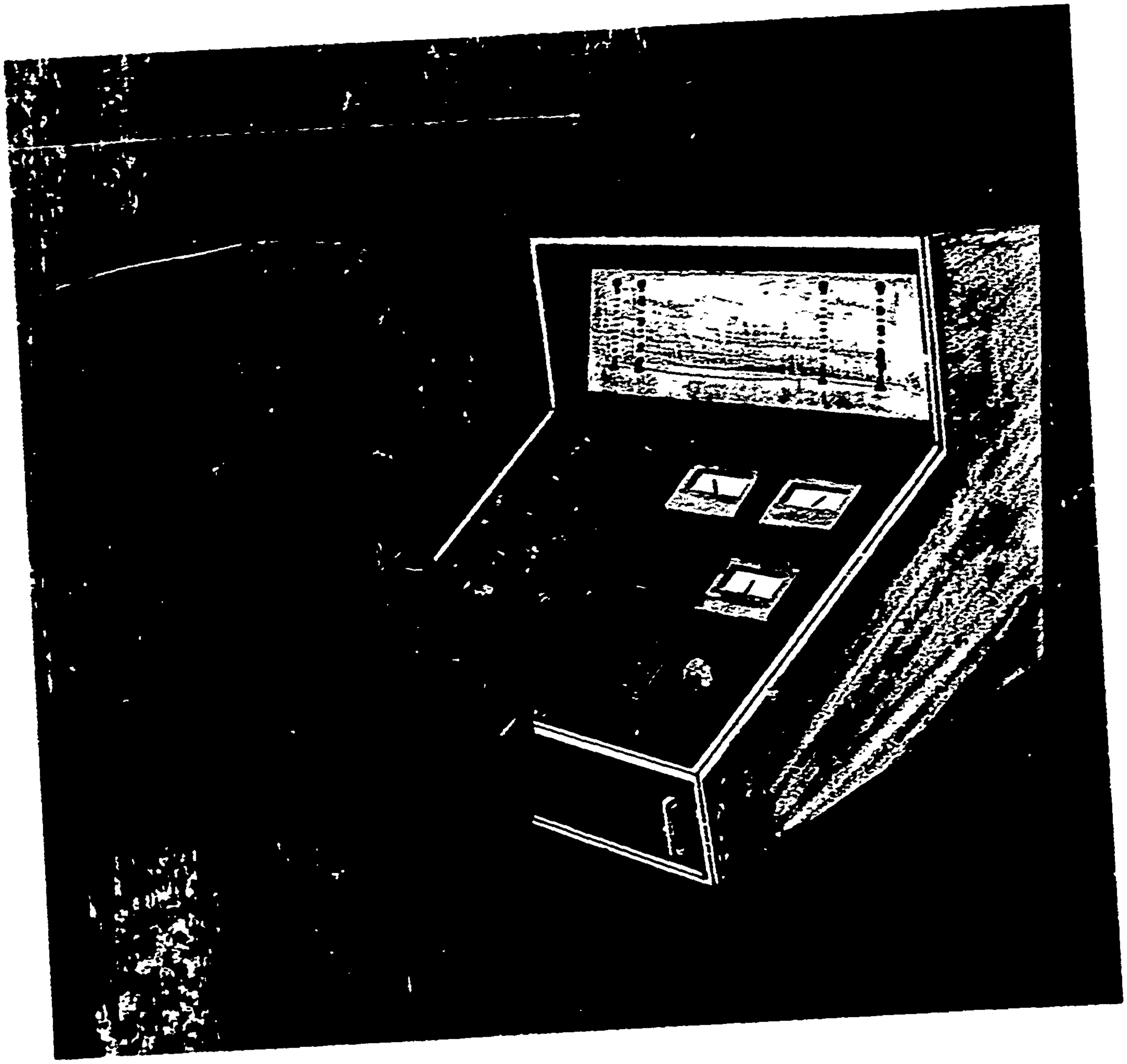


Figure 3-3. Shore Station Command Console

(U) The onshore console (Figure 3-3) contains the electronics necessary to synchronize to the data and demultiplex it from the SDC cable. The data are then available, in either digital or analog form, for onshore processing equipment. In addition, the console contains the command tone and calibration generators necessary to operate the system and evaluate its performance. The onshore console will give the operator control over the system and, by displaying all commanded parameters, a visual indication of the system status.

(U) 3.3 Choice of Operation Modes

(U) The ATA system has been designed to provide a maximum of flexibility so that a wide range of experiements can be conducted with the same physical hardware. This flexibility is essential since once the system is deployed, it is no longer accessible. In order to meet this goal, the system has been designed to interface both with a shore based operator and with shore based signal processing equipment. The operator interface consists of a command telemetry link which allows the operator to arbitrarily and independently select data from up to ten different sensors to be sent back to shore simultaneously. These ten sensors can be any combination of hydrophones and/or physical sensors such as substation depth and array tilt. All data sent to shore are digital data quantized to 12 bits. In addition, the operator has the option of independently selecting any one of four different preamp gain settings for each of the hydrophones in the system. The equipment interface consists of the necessary hardware to provide the digital data to the shore based processing equipment such as D/A converters, integrators, correlators, or beamformers. Since the data have been subjected to a minimum of processing in the array, the data are in a form which permits processing in any manner consistent with the experiment.

(U) 3.4 Signal Format

(U) A digitized data format was chosen for the transmission of signal data, over the interstation cable and through the SDC cable to the shore station, over other methods such as AM or FM, for the following reasons:

(U)
- In an AM/FM System, multiplexing circuitry is far more complex, requires far greater power, and many more individual parts are needed
- The additional complexity and greater number of parts significantly reduces the reliability of the substation
- Due to the number of different oscillators needed for multiplexing the signals on the line, the individual substations are no longer interchangeable with one another; as are the ones proposed.

(U) For the above reasons, simplicity, low power consumption, interchangeability and high reliability, a digital transmission format was chosen.

(U) 3.5 System Mechanical Description

(U) The Recommended Acoustic Test Array System consists of four substations, each with a ten-hydrophone vertical array. The substations are spaced along 5,250 feet of interstation cable. Inshore and seaward anchors maintain tension on the interstation cable to secure the system to the ocean floor. The inshore anchor will be located at the junction between the SDC inshore cable and the first 2,000 feet of interstation cable. The seaward anchor will be attached to and located approximately 2,000 feet seaward of the last substation by an auxiliary line.

(U) The configuration of the alternate Expanded Acoustic Test Array System will consist of eight substations each with a ten-hydrophone vertical array. The substations will be spaced along 23,750 feet of coaxial interstation cable. The interstation cable and anchoring configuration for the Expanded system will be the same as for the Recommended four-substation configuration. The Basic array is the same as the Recommended array except that only five hydrophones per vertical array is used, and the height above bottom is 1000 feet instead of 2000 feet.

(U) The inshore anchor will be a 90-pound high-tensile Danforth type anchor, having a minimum holding power rating of 2,900 pounds in soft mud. It will maintain the interstation cable tension without transferring the tension to the inshore cable. The anchor is to be attached to the junction betwe n the SDC and interstation cables with approximately 20 feet of chain.

(U) The seaward anchor will be a clump type concrete anchor, with embedded steel prongs, weighing approximately 2,000 pounds in water and 3,600 pounds in air. The anchor will be attached to the last substation with 2,000 feet of polyethylene jacketed, torque-balanced wire rope. A grapnel line approximately 22,000 feet long is to be attached to the seaward anchor. This line will be used to lay the system and provide a cable for retrieving the system. The grapnel line is to be torque-balanced polyethylene covered steel cable.

(U) The interstation cable which interconnects the substations will be a .55 inch OD torque-balanced coaxial cable having a minimum breaking strength of 15,000 pounds. Terminations and strain reliefs molded on the cable ends will connect the substations into the system and provide the required electrical and structural interface between the cable and each substation. The cable terminations can be interconnected to each other, as well as mated to the substation, thereby allowing the interstation cable lengths to be connected together for testing without a substation. This technique will allow several of the short sections of interstation cable to be wound on the same reel to permit electrical testing of the complete system and cable during any state of deployment.

(U) The substation houses a hydrophone array that is erected after the system has been implanted on the bottom. The vertical array cable and the series of hydrophones are to be packaged as a coil in the substation with one end secured to a cylindrical float, and the other end connected to the substation's watertight pressure vessel and anchor compartment which will house the substation electronics. After implantment and upon command from the shore station, the substation will release the float. The vertical array and cable will be payed out from the housing by the ascending float.

(U) The system is to be deployed from a ship heading on a straight course with the cable payout tension adjusted to provide a nominal horizontal tension component in the interstation cable of 1,000 pounds so that each substation is located at the proper spacing as determined by the length of interstation cable between substations. The initial length of the interstation cable from the SDC cable junction box can be varied to achieve the desired bottom elevations for the substations in the system and to compensate for minor variations in the end location of the SDC cable.

(U) 3.5.1 Interstation Cable

(U) The interstation cable will serve as both a mechanical and electrical link between substations and the seaward end of the SDC cable. As a mechanical link it will be used to lower the individual substations in the water and to horizontally position them on the ocean floor. As an electrical link, it will be used to transmit data from the substations to the shore station and to send commands from the shore station to the individual substations.

(U) The cable will be of coaxial construction as follows:

a) The center conductor will consist of seven (7) strands of .017-inch diameter annealed copper stranded to a nominal .051-inch diameter.

b) The insulation will be a heat stabilized, non-oxidizing high molecular weight polyethylene. It will be extruded over the center conductor to a nominal thickness of .064-inch.

c) The outer conductor will consist of two helical wraps in opposite directions of .002-inch thickness annealed copper.

d) The dc resistance of the inner conductor will be 5.4 ohms per 1000 feet.

e) The dc resistance of the outer conductor will be 2.3 ohms per 1000 feet.

f) The insulation resistance will be in excess of 1,000 megohms per 1000 feet.

g) The attenuation will be 1.1 dB per 1000 feet at 100 kHz.

h) The characteristic impedance will be 56 ohms.

(U) Over the basic coaxial cable there will be a barrier, double armor and jacket as follows:

a) The barrier will be a high molecular weight, low density polyethylene extruded to a nominal thickness of .049-inch.

b) The inner armor will consist of eighteen (18) strands of .050-inch diameter galvanized high strength steel applied in a right lay.

c) The outer armor will consist of thirty (30) strands of .038-inch diameter galvanized high strength steel applied in a left lay.

d) The jacket will be a black high molecular weight, low density polyethylene extruded to a nominal thickness of .040-inch.

e) The finished cable will have a nominal diameter of .55-inch.

f) The breaking strength of the cable will be in excess of 15,000 pounds.

g) The cable will have a minimum bend radius of 6 inches without being overstressed.

(U) 3.5.1.1 Cable Termination

(U) Each section of interstation cable will have a cable termination installed on each end, as shown in Figure 3-4. This termination will serve several functions. It will serve as an electrical feedthrough and a pressure proof penetration as well as a point for termination of the cable armor.

(U) Within the body of the termination, the insulation, barrier, and jacket will be separately bonded to a metal insert. This technique will effectively block any leakage path that could cause a short between the center and outer conductors due to hosing effects.

(U) By using a termination in lieu of a connector, the number of parts and seals are held to a minimum, thus increasing the reliability of the system. Exclusive of the internal seals, which would be common to any connector, the termination has only two seals: a primary face seal, and a backup radial seal. Most cable connectors require these seals and similar seals for a mating bulkhead connector. Two additional seals are also required for the bulkhead closure. The cable termination, therefore, eliminates four seal areas, greatly reducing the chance for failure.

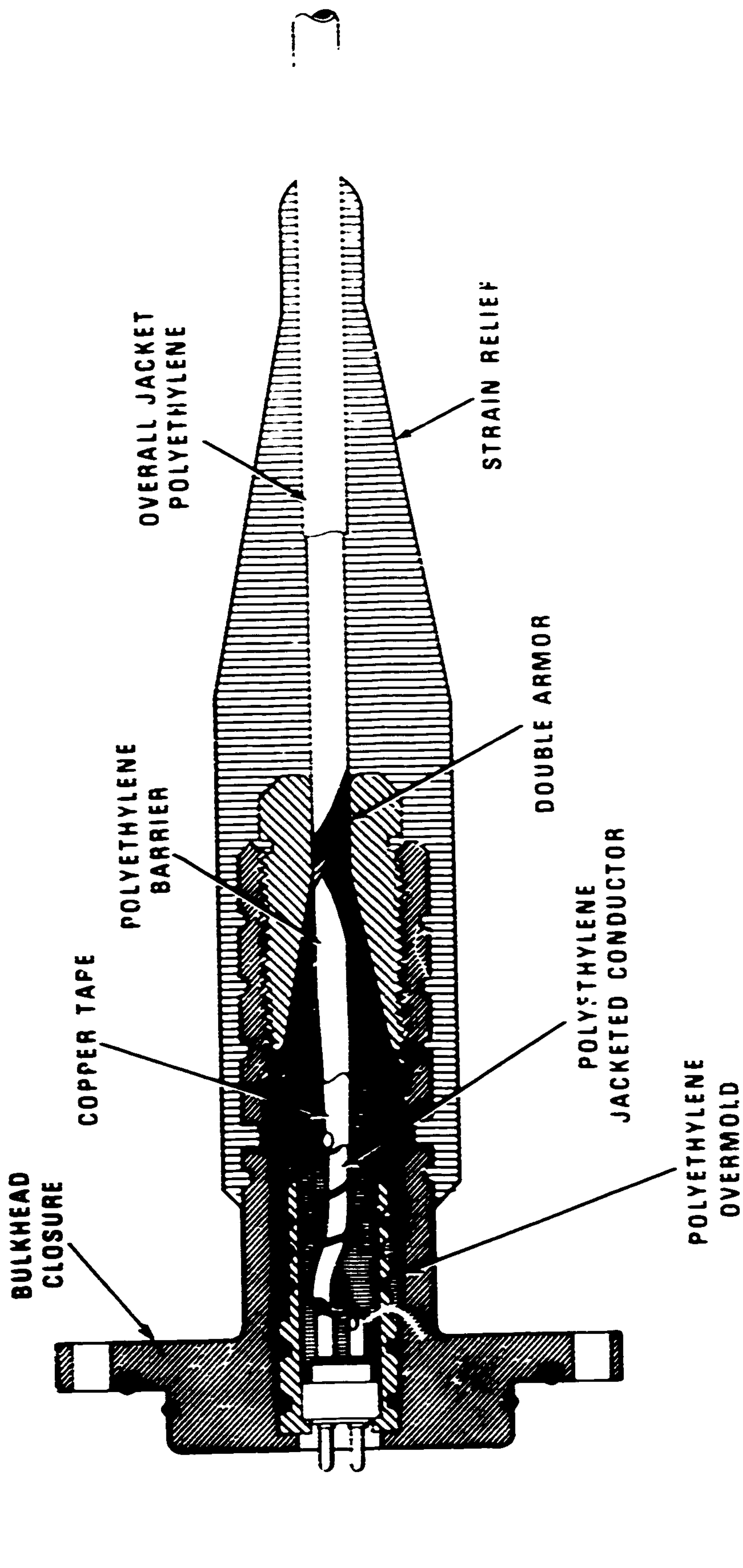
(U) 3.5.1.2 Cable Environmental Survivability

(U) The primary biological threat to the interstation cable in an ocean bottom environment will be from marine borers. Based on data available, it has been determined that the .040-inch thick jacket of high molecular weight, low density polyethylene will provide protection from this hazard.

(U) It is recognized that fish bites will be a potential hazard during implantment of substations and interstation cable. The double armor steel outer strength member, however, will provide excellent protection against fish bites.

(U) 3.5.2 Basic Acoustic Test Array Substation Configuration

(U) A 1,500-foot vertical array substation used in the basic array is shown in Figure 3-5. It consists of a combination anchor and electronic housing, an electrical cable assembly, a



(U)

Figure 3-4. Cable Termination

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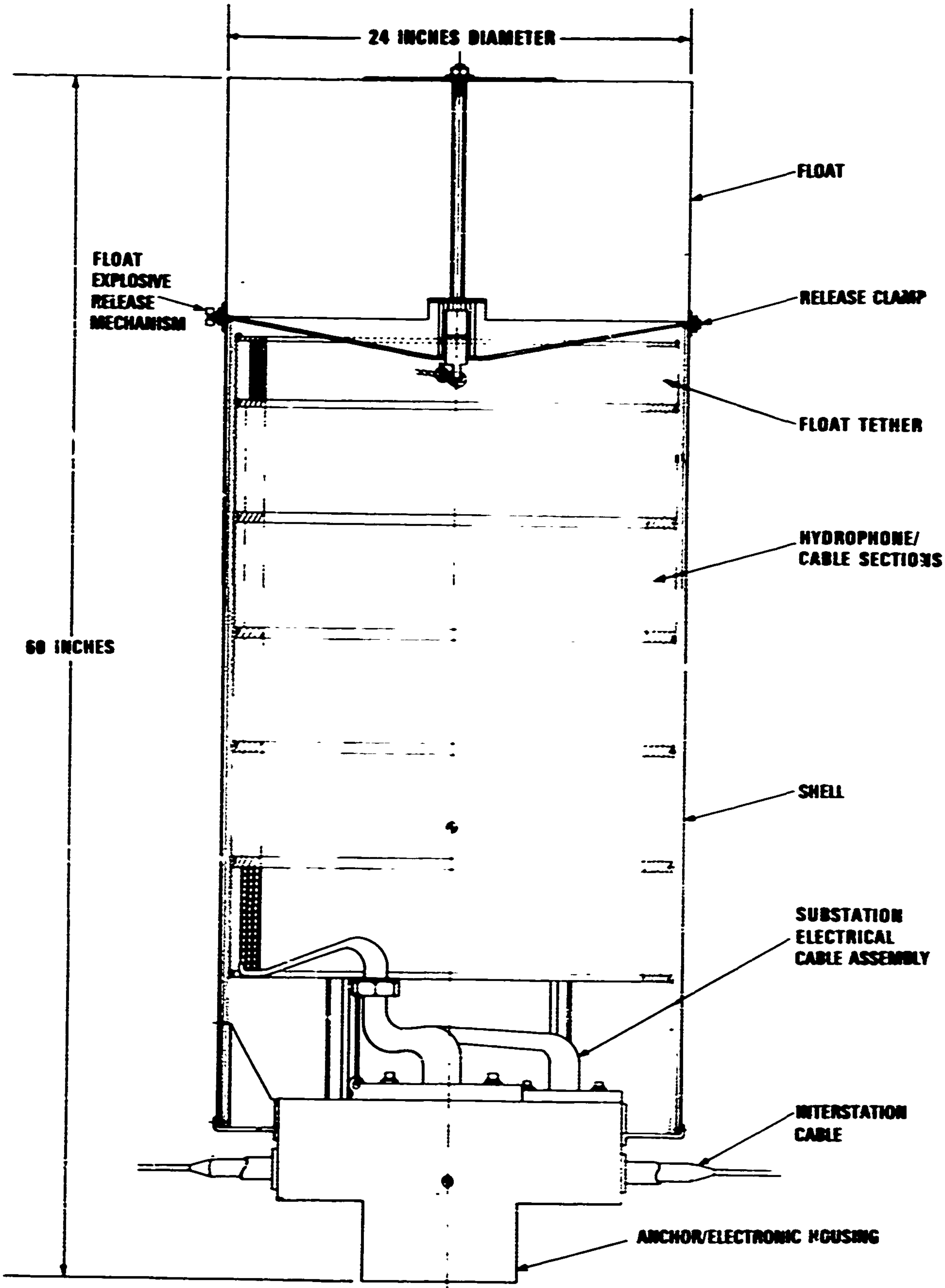

Figure 3-5. Basic Substation

(U) substation depth sensor, an array cable and hydrophone package, a cylindrical shell, a float release mechanism, and an array float.

(U) The substation will be approximately 24 inches in diameter and 60 inches high. The air and in-water weights will be approximately 874 pounds and 250 pounds, respectively.

(U) Materials used throughout the substation will be selected for their suitability in an ocean bottom environment, and their mutual compatibility.

(U) 3.5.2.1 Anchor/Electronic Housing

(U) The array electronics will be housed in the substation anchor (Figure 3-6). This approach will help to reduce cost and complexity of the substation. There will be three cavities in the anchor with individual closures and seals. Two will house electronics associated with the hydrophones. The third and smallest will house the electronics that make up the repeater.

(U) In keeping with the redundancy of the electronics, each of the large cavities will house one-half of the array electronics. This will ensure that, in the unlikely event of a closure seal failure, one-half of the array will continue to operate.

(U) 3.5.2.2 Substation Electrical Cable Assembly

(U) A molded cable assembly will interconnect the array electronics and repeaters with the substation float release mechanism, depth sensor and the vertical array cable. The portions of the cable assembly that go to the array electronics and repeater will be molded to and form the bulkhead penetrations that form the closures for the electronics and repeater housings. The portions that go to the depth sensor and float release mechanism will have appropriate watertight connectors. The connection to the hydrophone array will have an attachment point for securing the array to the anchor.

(U) By making the electronics housing and repeater housing closures a part of the cable assembly, seals associated with cable connectors, bulkhead connectors, and bulkheads are eliminated.

(U) 3.5.2.3 Substation Depth Sensor

(U) On each substation there will be a hydrostatic pressure sensing device. This sensor will be used to determine the actual depth of each substation after it is implanted. With this information transmitted over the data link to the shore station and, knowing the length of hydrophone array cable between the bottom hydrophone and substation electronic housing, the vertical location of the hydrophone array can be determined.

(U) The hydrostatic pressure sensor will be located external to the electronic housing to eliminate a penetration of the housing. The electrical leads from the sensor will be part of a cable assembly with the electrical leads to the float release mechanism. This cable assembly will form part of a larger cable assembly which interconnects the three electronic assemblies.

(U) 3.5.2.4 Vertical Array Cable Packaging

(U) The 1,000-foot continuous length of hydrophone array cable in the basic array will be wound into a coil in a manner that will facilitate attachment and free deployment of the hydrophones and cable. This will be done by winding each 200 feet of cable between hydrophones into separate but connecting sections of the coil.

(U) As a part of the cable array coil, there will be a 500-foot length of braided, 1/4-inch diameter, dacron line. It will also be wound into coil form and will connect the top hydrophone to the float. The dacron line will at least equal the breaking strength of the array cable but, having a smaller diameter, it will create less drag on the array. This reduction in drag area will permit a somewhat smaller float than would be required using a line or cable the same diameter as the array cable. The weight in water of the dacron line will be 2.5 pounds, much less than the equivalent length of array cable, thereby further reducing the size of the float.

(U) The elastic characteristic of the dacron line also permits it to act as a compliance as the upward movement of the float is arrested by the payed-out length of array cable.

(U) During the winding of the coil, both the dacron line and the array cable will be back-twisted. This will cancel the twist per turn in each that is a consequence of axial payout from a coil. Backtwisting is a proven and acceptable technique and was proven on Mk 37, 45 and 48-1 torpedoes. The result is a cable or line that is rotationally stable about its longitudinal axis during payout. There is a definite benefit to this stability in that the vertical array will not have to rotate as it rises. Once fully erected, it will not tend to oscillate rotationally as a result of cable twist or motion.

(U) To achieve smooth, reliable and uniform erection of the hydrophone array, the line and cable will be slightly restrained during payout. The restraint will be achieved by fabricating the array coil with a frangible ureaformaldehyde adhesive. This material will effectively restrain individual turns of cable from dislodging and paying out prematurely. Its component parts can be proportionally mixed to impart a predictable and uniform restraint to the line and cable.

(U) The hydrophone cable will be procured with appropriate terminations. This will permit the assembly to be adequately tested by the manufacturer to assure a high reliability product.

(U) 3.5.2.5 Hydrophone Packaging

(U) Each hydrophone will nestle in an individual cushion as shown in Figure 3-6. The cushion will have a dual purpose. First, it will protect the hydrophone from shock and vibration that might occur during handling and transportation of an assembled substation. Second, it will firmly hold the hydrophone in position until its turn in the array deployment sequence.

(U) The cushion will be segmented and premolded, the material being low-density, expanded rigid polystyrene.

(U) 3.5.2.6 Float

(U) In order to maintain the erected hydrophone array at the required vertical orientation, an acoustic test array cable tension of 50 pounds minimum will be supplied by a float with approximately 110 pounds of buoyancy. Syntactic foam having a density of 34 pounds per cubic foot has been selected as a suitable material for the float. This material can be cast

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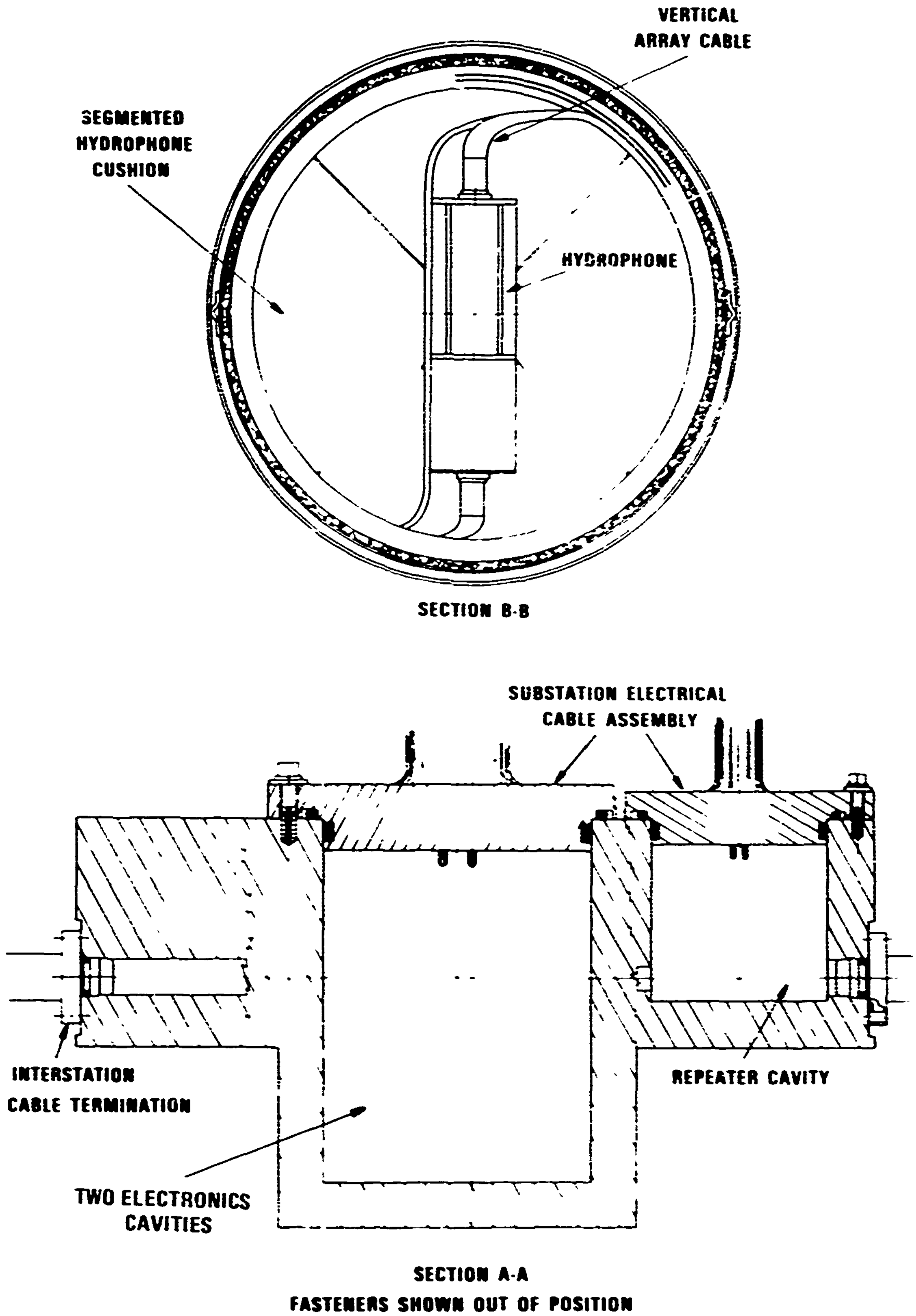

Figure 3-6. Anchor/Electronic Housing

(U) into the desired configuration with a minimum amount of machining and can be supplied at a reasonable cost. It can also withstand the hydrostatic pressure expected at the selected implantment site for the array.

(U) The float will be attached to the array by 500 feet of braided dacron line. The dacron line will act as an energy absorber and absorb any undue deceleration forces generated by arresting the payout of the hydrophone array as it reaches its deployed length.

(U) The float will be cylindrical, approximately two feet in diameter by one foot high. The configuration of the float has been selected as a good combination of maximum buoyancy and minimum drag. Also influencing its shape were methods of attaching and releasing it from the substation.

(U) 3.5.2.7 Float Release

(U) The float will be released from the substation by a command signal from the shore station. This signal will activate an explosive release bolt. When this event occurs, the V-clamp band holding the float and substation flanges together will separate and fall away from the flanges. The firing circuit for the explosive release will consist of dual explosive cartridges, a capacitor, and electronic switching. Cartridges requiring low firing current are available and can be activated by a 700- to 1,000-microfarad capacitor.

(U) The electronic switching will short the cartridge leads to prevent inadvertent cartridge activation. Upon command from the shore station, the capacitor will be charged. Upon a second command, the electronic switching will simultaneously arm the circuit and discharge the capacitor current into the cartridge and activate the explosive release bolt.

(U) Personnel safety is of paramount importance. In addition to shorting of the cartridge until the moment of activation, two mechanical safety features will be provided. The first will be a captive separation feature tha retains the ruptured bolt. The second will be a locking clamp bar that holds the V-clamp together during assembly of the explosive bolt mechanism. This locking bar will remain in place until the substation is in water. It will be removed by a diver during the substation deployment sequence as discussed in Appendix C.

(U) 3.5.2.8 Vertical Cable Payout

(U) Payout of the hydrophone array will be initiated by the released float. Once started, payout will be continuous until the entire substation vertical array is erected.

(U) As the float rises, the first item to pay out is the dacron line. The lower end of the line is attached to the vertical cable strain member slightly above the top hydrophone and pulls it free from its cushion when the line has all payed out. Payout of array cable is then started. As the hydrophone is pulled free of its cushion, the cushion will separate into its segmented parts. The parts will be forced out of the substation by cable payout. In the event that cushion segments become lodged in the substation, the action of cable paying out will fragment the low density polystyrene.

(U) Each hydrophone and associated portion of array cable will pay out in a like manner until the entire array is deployed.

(U) 3.5.3 Recommended and Expanded Substation Configuration

(U) The Recommended and Expanded substation is shown in Figure 3-7. It contains the same type, longer hydrophone array and an array cable payout device. This substation will be approximately 30 inches in diameter and 100 inches high. The air and in-water weights will be approximately 1100 pounds and 320 pounds, respectively.

(U) The addition of the five hydrophones will increase the array height from 1,500 feet to approximately 2,500 feet, including the float.

(U) The second additional component is the auxiliary payout device which will permit payout of additional array cable. The purpose of this device is best explained by outlining the system implantment and array erection for the expanded system.

(U) The system is designed so that it can be implanted on a sloping ocean floor. During system implantment, some substations may be implanted in shallower water, others in the deeper water.

(U) In order to have all hydrophones at uniform depth, vertical adjustment of the deepest substations in the array may be necessary. In operation, the vertical location of the hydrophones of the substations is determined by the substation depth sensors and the known lengths of array cable between the substation anchor and the lowest hydrophone.

(U) When the hydrophones of the adjustable array height substations are deployed, a 200-foot length of array cable will separate the bottom hydrophone from the substation anchor. A depth sensor located in the substation will transmit, upon interrogation, the array depth information. Upon command from the shore station, additional array cable will be payed out to decrease the array depth so that all arrays are in the same relative vertical orientation.

(U) For sake of simplicity, the payout device will release a fixed amount of cable per command. This will reduce the possibility of too much array cable being payed out since no means of reeling in cable will be provided.

(U) Figure 3-7 shows the orientation and configuration of the payout device and the additional length of array cable. Power to operate this device will come from shore. A relay in one of the electronic housings will transfer the low power command signal to the solenoid within the payout device.

(U) When the solenoid is momentarily retracted, a cam will be released, permitting the rotating arm to complete one revolution. When not rotating, the arm effectively restrains payout from the attached reel of array cable.

(U) Once the desired vertical orientation of the array is achieved, no electrical power is required to hold the orientation. The extended solenoid pin locks the cam and rotating arm. In addition, a command from the shore station will disable the payout command system preventing inadvertent cable payout.

(U) 3.6 Techniques to Insure Reliability of the ATA System

(U) In order to insure the high reliability necessary for the ATA system, certain controls must be exercised over parts suppliers, designers and manufacturing.

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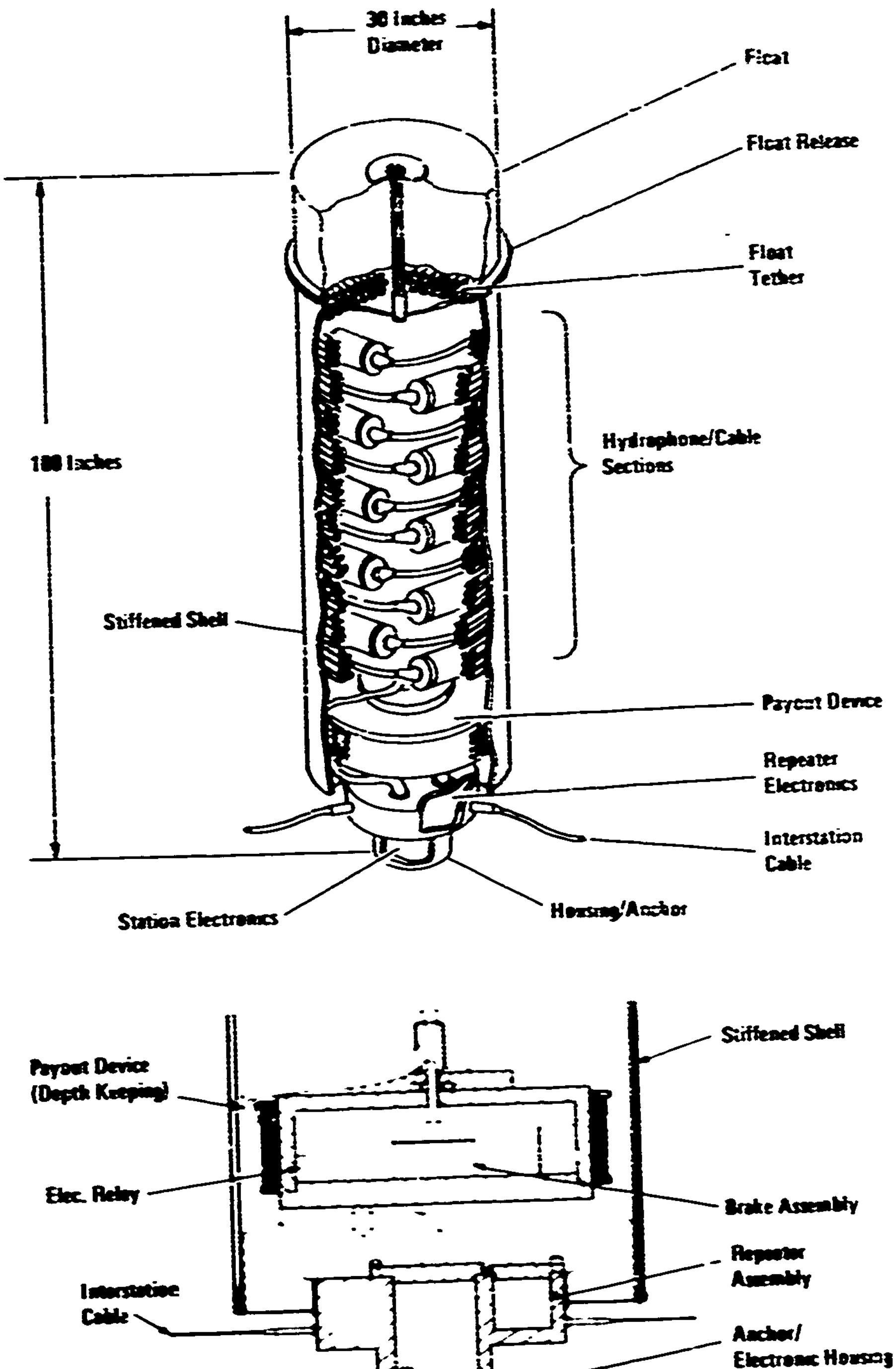

Detail of lower section of substation

Figure 3-7. Recommended and Expanded Substation

(U) Electronic parts selected for the ATA are of the highest quality and this quality is tightly controlled by the applicable MIL-standards and specifications.

- Integrated circuits used are tested to MIL-STD-883 as Class A devices.
- Semiconductors are JAN-TX devices.
- Resistors and capacitors are selected from available established reliability types.
- All work performed will use MIL-STD-16400F as a guide.

(U) During the design phase, the reliability of the design is assured by:

- Prediction—A reliability prediction will be made during the design cycle. This prediction will be made in conjunction with the detailed reliability design review. Failure rate data for the reliability prediction will be taken from RADC-TR-67-108, Vol. 2, MIL-HDBK-217A, and Raytheon's component data bank.
- Design Review—Since reliability presumes a sound design concept, specialists of various backgrounds will be conducting a formal design review to eliminate potential sources of unreliability in the early design stage. This review includes a component parts review, stress analysis and computer programs to analyze the effect or parameter tolerance and drift on the circuit performances.
- Mission and Environmental Study—A clear understanding of the conditions of service usage is a prerequisite to the design of reliable equipment. Therefore, a knowledge of the environments to be experienced by the ATA subsystem, its constituent assemblies and piece parts is essential if reliable operation is to be obtained. The environmental study will develop environmental mission profiles which will be used for the selection of reliable parts in the determination of optimal packaging configurations, and the development of realistic in-plant environmental test plans. Non-operating considerations such as storage, handling, packing, shipping, and packaging materials, as well as the operating environments such as temperature, shock, vibration, noise, humidity, etc., will be reviewed in detail. Information will be obtained from environmental studies conducted by the Navy and from Raytheon's own experience in the study of ocean environments. This provides a valid basis for establishing the essential capability of parts and materials to be used in the equipment. In this regard, the analysis contributes to the fundamental criteria for achieving product reliability.
- Failure Mode Effects and Analysis—This effort identifies the various modes of failure that can occur and their relative frequency of occurrence. The purpose of conducting a failure mode analysis is to review and rejustify the concepts used used in the design, and point out areas for design improvement and corrective action.

(U) During manufacture, further quality control and inspection is exercised to ensure sufficiently high quality results.

4.0 PHYSICAL DEPLOYMENT

Prior to the actual deployment of the ATA System, certain predeployment operations must be carried out in order to insure the successful deployment of the final system. These predeployment operations include the following:

1) Approximately three months into the ATA contract, the SDC cable must be raised and fully checked out. At that time a single set of electronics will be attached to the cable. This test station will contain part of the electronics that will be contained in the final system and at least two hydrophones. While this test station is still on the deck of the ship, it will be powered from shore and the integrity of both the electronics and cable will be verified. Once this verification is received, the test station and cable will be lowered to the ocean floor. Over the course of the next three to four months, the test station will be monitored on shore using both calibration signals as well as real data received by the hydrophones. This will allow the integrity of the SDC cable to be monitored over a significant time span as well as allow the electronics to operate in a "real life" environment. At the end of this monitoring period, the test station/SDC cable must be raised again and the integrity of the mechanical package will be carefully examined for signs of possible failure. The end result of this exercise will be increased confidence in both the electrical and mechanical designs as well as in the SDC cable, and the results of these tests will be known in sufficient time to allow for modifications of the final system should they prove necessary.

2) Prior to the deployment of the final system, a live vertical array will be practice deployed in order to train the implantment crew. At this time, contingency plans should be practiced in the event that some catastrophic failure in either the system or the implantment equipment should occur. It must be insured that the system will not be lost for any reasons and that it can be retrieved during any phase of implantment.

3) Shallow water testing of the vertical array payout technique also must be performed before deploying the final system. Divers can be used to observe and verify that the payout technique is successful. It must be insured that there is little chance that the array could tangle during payout.

4) The array presently installed off Bermuda and which is connected to the SDC cable must be removed prior to implantment of the ATA system. This is to avoid any possibility that the two arrays will become intertwined. This will take place when the SDC cable junction box is raised, approximately three months after the start of the contract.

4.1 Implantment Concept

The concept developed to implant the Acoustic Test Array Systems shown in Figures 4-1 and 4-2 utilizes basic and relatively straightforward cable laying techniques to deploy and anchor the system on the ocean floor. The implant plan will be designed to deploy the system in test-proven, sequential steps that will enable the system to be electrically monitored during each phase of implantment. The implantment of the system will require the use of one cable laying type ship. Other implant methods were considered, but the one ship deployment concept described below was considered optimum for the system based on SDC cable and interstation cable tensions, the system implantment accuracies, system retrievability, implantment cost and the resulting complexity when more than one ship is involved.

The final implantment plan will provide details of the specific cable tensions and ship position as well as course and speed during all phases of the deployment. In addition, the plan will specify the detailed ship characteristics required, the method for handling and towing all system equipments and the method for performing all deployment operations. Plot boards and charts will be required to verify and assist in controlling the anchor position and ATA interstation cable catenary during system implant. Casualty guidelines will be generated for weather, deployment vessel equipment casualties and ATA system equipment failures to complement the implantment plan.

The selection of a ship and a crew with the capabilities required to deploy the ATA system is a major factor in successfully implanting the system. A cable laying ship such as the R/V F.V. HUNT owned by TRACOR MAS with characteristics as specified in Appendix D is capable of deploying the system using a cable engine, crane and an auxiliary winch which can maintain the required cable tension while deploying substations and anchors over the side. Using a ship such as the R/V HUNT, the interstation cable would be stored in reels on deck and the cable would pass over a back tensioning device or jockey wheel to a hydraulic powered engine. From the cable engine the cable would then be payed out over the bow sheave on the ship. This method for paying out marine cable is a standard cable laying technique.

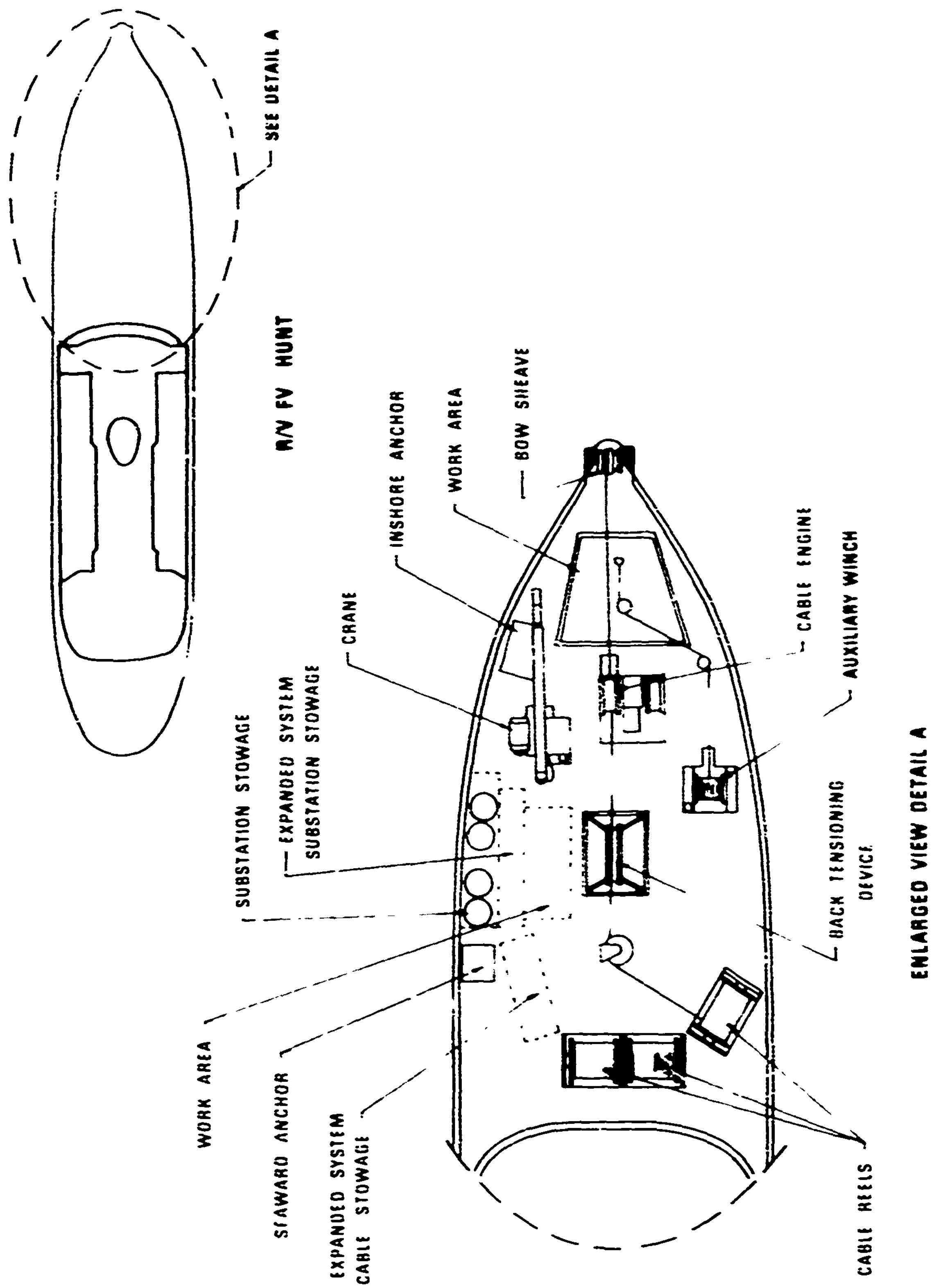

Figure 4.1. Implant Ship Deck Layout

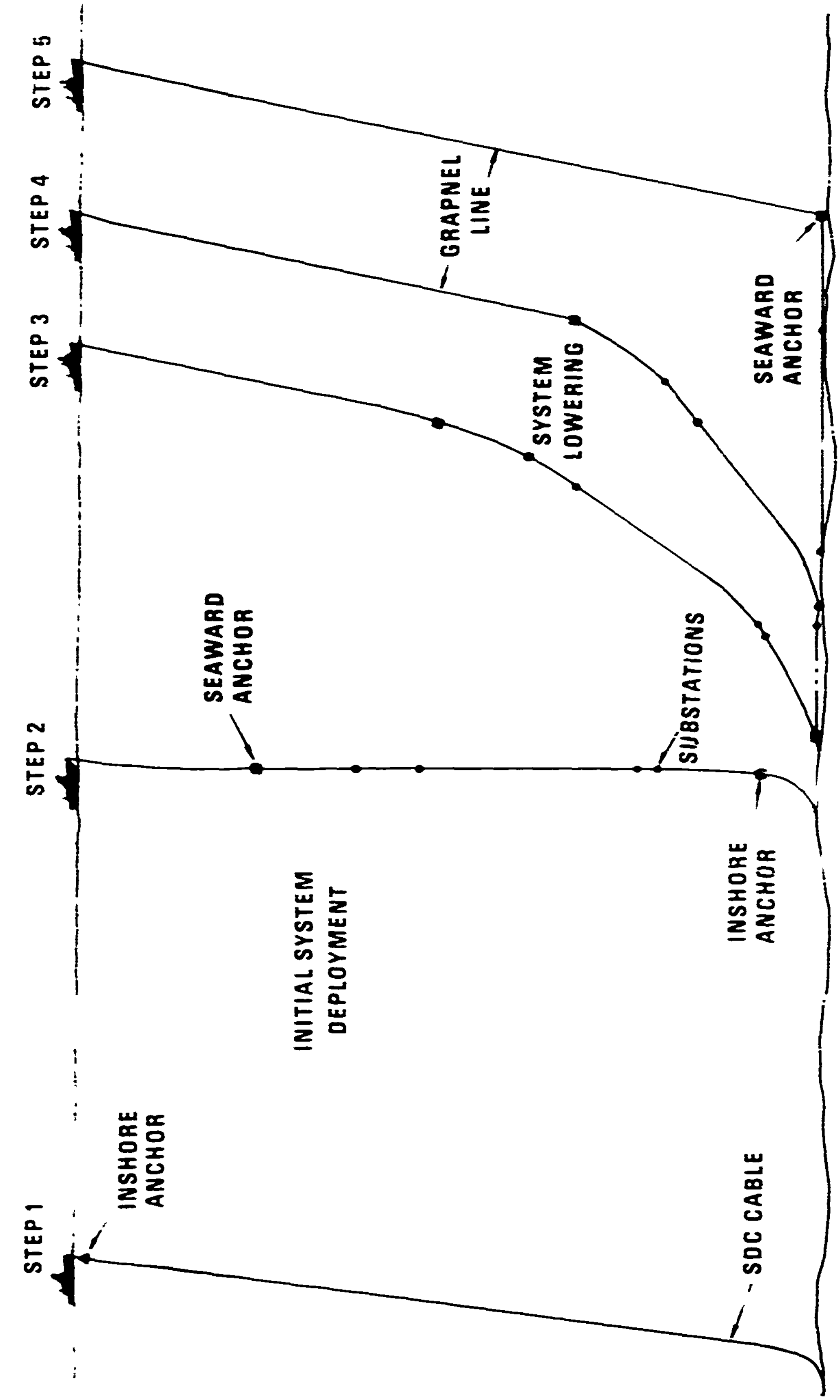

Figure 4-2. System Deployment Concept

Prior to the start of the system implant, all equipments to be deployed will be positioned on the foredeck for easy access as shown by an artist's concept, Figure 4-1. The ATA interstation cable will be supplied on reels in lengths that are a function of the spacing between substations. More than one cable length may be wound on the same reel depending on the cable lengths and reel size. The cables on the reel would be interconnected at the cable terminations molded on the cable ends. The payout mechanism will be configured to pass the cable and its molded connectors without damage. The cable storage reels will be mounted on special racks that will have a braking and rewind capability for the cable reel. The substations and anchors will be positioned on the deck so that they are easily accessible to the handling equipments. The substation will be stowed vertically in special mounting racks that will facilitate their handling and testing during deployment.

4.2 General Implantment Description

The implantment method which is shown as an artist's concept in Figure 4-2 utilizes basic cable laying techniques to implant the system. It is estimated that under good weather and sea conditions the Basic or Recommended ATA System using the described method could be implanted within 15 hours after connection to the SDC cable. The time to implant the Expanded system after connection to the inshore cable until release of the grapnel line is estimated to be 22 hours.

A description of the implantment method is provided below based on the step by step procedures shown in Figure 4-2. A description of the system electrical operation during the deployment is also provided.

4.2.1 Step 1. Cable Attachment and Deployment

The implant of the ATA system starts with the attachment of the system to an inshore cable. An existing inshore/SDC cable located in the waters off Bermuda appears feasible for attachment to the system. Verification of the electrical and in-water properties of this cable is required prior to attachment to the ATA system.

A feasible location for joining the ATA system to this existing inshore cable is at the inboard end of the line drivers that were originally laid with the cable. The cable at this location is armorless and is located approximately 4 nautical miles seaward of its chain type inshore anchor.

The ATA system attachment to the cable will require that the cable be retrieved and the cable end prepared for attachment to the ATA system junction box. The junction box design provides for attaching the SDC cable in a manner similar to that used in the existing line driver housing. The attachment must provide an electrical and structural connection to the junction box. In addition, a preformed steel covering must be added to a short length of the unarmored SDC cable to protect the outer jacket from the ATA system inshore anchor and its chain attachment to the junction box.

The ATA interstation cable will enter the junction box using a watertight penetration and strain relief which is secured to the junction box along with the inshore anchor chain. The anchor chain is to be secured to the junction box using a shear pin. This shear pin will separate the cable junction box from the anchor if the anchor holding force should exceed a safe working load on the ATA interstation cable in case system recovery is desired.

With the system attached to the SDC cable, the shore station will power the system and monitor its performance during the implant. A well prepared ship to shore communication plan will be followed to remove power from the system when cable or substations are being added in the system and to coordinate any abnormalities in system power or data.

4.2.2 Step 2. Begin System Deployment

After attaching the interstation cable to the SDC cable and anchor, system deployment will begin with the lowering of the inshore anchor to the proper position while laying the SDC cable toward the required position of the seaward anchor. The cable tension will be adjusted to that required to lay the SDC cable. The SDC cable will be laid with from 5 to 15 percent slack, depending on the bottom configuration. The position of the inshore anchor is to be periodically monitored and charted, along with the amount of cable payed out and the exact ship position. As the inshore anchor approaches the bottom, additional cable

slack will be payed out so that the inshore anchor can be positioned and secured to the bottom without applying a tension that will drag the SDC cable across the ocean floor. It is during this phase of the operation that the interstation cable undergoes its greatest tension. A safety factor greater than 2.5 is included.

4.2.3 Steps 3 and 4. System Lowering

After the inshore anchor has been secured to the bottom, the cable payout tension will be adjusted to provide a 1,000-pound horizontal tension component to the interstation cable on the bottom. At this stage of the implant, all the components of the Recommended or Basic ATA System will have been lowered into the water and the deployment vessel will be paying out grapnel line. With the Expanded System, the vessel will pay out a longer length of interstation cable. While placing the substation on the ocean floor the deployment vessel must continually control its position through all stages of implant to accurately position the system on the ocean floor. The interstation cable design requires that no excessive tensions be exerted on the ATA cable and that no slack cable be laid. When the cable is stoppered off for adding substations and anchors, redundant cable attachments to auxiliary winches will be employed to prevent cable loss or damage during these operations.

4.2.4 Step 5. Array Anchoring

When the seaward anchor reaches the bottom and the electrical performance of the system is verified to be proper, the auxiliary line will be released from the ship. Prior to the release of this line, the deployment sequence can be reversed and the system retrieved without grappling equipment or other special recovery equipment. With the system positioned the erection of the vertical acoustic arrays from specific substations will be initiated. The vertical arrays will be erected in a sequence based on the current profiles so that the current will carry the erected arrays away from the packaged arrays.

The details for accomplishing the above implantment phases from the deployment ship and system implant requirements including required ship characteristics are provided in Appendix C.

4.3 Acoustic Test Array Operation During Implant

The Acoustic Test Array will be operated during system implant in order to monitor continuously array electrical and mechanical integrity. Special safety precautions will be observed in handling the array and its interstation cable. The cable will be electrically grounded at both the ship and shore station prior to interconnection of substations and/or cable disconnect to protect personnel.

Prior to the SDC cable connection, the system equipment will be interconnected on the ship. The array will be operated from shore as soon as the SDC cable connection and interstation cable are connected at the junction box. After proper system operation is verified by means of calibration signals, power will be turned off to disconnect the first substation and permit the first section of interstation cable to be payed out from its reel. After 2,000 feet of this cable has been payed out and the first substation reconnected to shore, the system equipment will be monitored. This will provide substation power and permit substation operation and checkout in the "master station" mode during system implant. As subsequent stations are deployed they will be operated in the "master station" mode and the shoreward stations will be operated in the "slave station" mode.

During system implant the substation depth and leak detectors will be continuously monitored. Hydrophone gain commands and calibration signals will be transmitted to the substations to verify hydrophone continuity and proper operation of substation electronics. Each time a new substation is inserted in the line it will be tested while it is still on deck, with operation continuing after submergence.

Once all the substations have reached the ocean floor and are positioned as desired, the vertical arrays will be erected. This is initiated by command from the shore station, with individual commands for each substation. The command actuates the explosive bolt that releases the float from the anchor, the float then rises, pulling the vertical array out of the substation. A tilt sensor in the lower part of the array can be monitored to indicate completion of payout and final array configuration.

A successful implant is completed for the recommended or expanded array when one additional operation occurs. After all the substation's arrays have been erected, depths of all arrays are compared. It is desired to have all hydrophones in a horizontal layer at the same depth within ±50 feet. Those arrays that are deeper will be commanded to pay out incrementally more cable until they are within tolerance. An additional command will then lock all arrays in place, disabling the incrementing capability. The system is then ready for normal operation.

4.4 Prototype Testing and Crew Training

The final implant plan will reflect the optimum implantment techniques that will be developed from actual handling and in-water testing of the system developmental and prototype equipments. After the implant technique has been developed and demonstrated by successful developmental at-sea tests, the crew of the vessel selected to implant the final system will be trained. This will require the ship's crew to perform the required sequential implantment steps with prototype equipment until they can repetitively demonstrate successful completion of the system implantment, including the erection of substation vertical arrays.

A comprehensive test plan will be developed including a detailed communication plan and a program conducted to test and evaluate fully in-water performance of the Acoustic Test Array System and develop the optimum implantment technique.

To verify the integrity of the existing SDC cable, the SDC inshore cable must be raised early in the program (by GFE) to ascertain the usability of the existing cable with the Acoustic Test Array System. It would be desirable at this time to implant a substation test unit at the end of this cable in the actual sea environment for a period of three to four months before full deployment takes place. The test unit would be designed to enable various seal design configurations to be evaluated in the environment to determine an optimum substation design. This test would enable a float, hydrophone, electronics, and interstation cable to be evaluated in the actual sea environment.

Also early in the program, payout developmental testing of the vertical array cable will be performed in shallow and deep water to evaluate various cable and hydrophone packaging concepts. The optimum developed packaging concept will then be tested for required payout and electrical performance characteristics. Payout testing of the interstation cable will also be evaluated in the laboratory prior to at-sea developmental tests.

Laboratory acceptance testing and environmental testing of all prototype and final system components will be performed prior to at-sea testing and implantment. Cable will be tested at tensions based on the implantment dynamic cable load analysis and the electrical testing of connectors and cable, electronic components and assemblies will be performed. Environmental tests will be conducted on major assemblies to evaluate their performance under shipboard vibration, temperature extremes and temperature shock conditions, and then under the extreme hydrostatic pressure environment. The temperature shock test will verify that the system equipment will operate when immersed in the sea after stowage on the deck in the sun. All cables, connectors and substations will be hydrostatically pressure tested in their finished packaged condition.

Developmental field testing will be performed at sea to evaluate the substation vertical array payout and the deployment techniques for all major system components. Testing will be conducted in both shallow and deep water. Shallow water tests will be used to evaluate anchor and substation deployment. The anchor and substation underwater bottom position configuration will be examined by diver personnel from deployment ship in tests conducted in water up to 100 feet deep. Deck handling of all system equipments and the electrical testing required during deployment will be developed and verified during the developmental testing conducted on the cable laying vessel. Deep water testing will be conducted using prototype and simulated equipments to verify the ability of the crew and ship to deploy and retrieve the system efficiently and accurately.

Upon recovery of the test unit from its deep water test bed and completion of the at-sea developmental tests, the final system configuration will be determined. Training of the crew will be conducted using prototype and simulated equipments modified to the final system

configuration. The interstation cable used for crew training and final system deployment tests will be the same design as used for the system implant. The crew and ship will demonstrate the capability to deploy repetitively the ATA system in the proper sequential steps using the prototype equipments prior to the final system implant.

The implantment plan will be continually updated through all phases of testing and then finalized prior to the final implantment operation. The final implantment will be conducted in the same manner that the crew and ship have previously performed on at least two test operations under similar weather and sea conditions.

(U) 5.0 ELECTRONIC DESIGN

(U) Shown in Figure 5-1 is a functional block diagram of the ATA system electronics. The system consists of signal processing electronics, variable gain preamplifiers, A/D conversion circuitry, and data telemetry electronics. This block diagram also includes circuitry for command generation and reception, power distribution, and data transmission. Each of these functional elements of the system will be described in the ensuing subsections.

(U) 5.1 Data Telemetry

(U) The erectedRecommended Acoustic Test Array will consist of 40 hydrophones suspended above the ocean floor. The output of each hydrophone will be preamplified and transmitted down a vertical cable to a substation. At the substation, the hydrophone data will be converted to a digital signal and transmitted to shore via an electrical coaxial cable. There are two types of cable, an inshore 45-mile section of SDC cable previously laid, and the new interstation cable which connects the SDC cable junction box to the substations. These cables will simultaneously accomplish three functions:

1) Transmit direct current power from the shore to the substations
2) Transmit tone command and calibration signals from shore to control the substations
3) Telemeter digital data from substations to shore.

(U) In addition to the hydrophone data, a depth sensor and a pair of tilt sensors will be located at each substation and their outputs will also be available for analog-to-digital conversion and transmission to shore. Leak detectors located within each substation cavity will provide digital outputs on substation pressure integrity. The digital signals from up to 10 data sensors (hydrophone, depth or tilt) will then be A/D converted and telemetered to shore. At the shore station, the data is available in digital form and may be converted back to analog for recording and display. The 10 sources will be selected from shore by means of a command link that will operate simultaneously with the data telemetry link. The commands and telemetry, which are flowing on a single conductor, will be separated by filtering. Commands will be transmitted as 100 Hz tone pulses, while the digital data rate will be 93.600 kHz.

(U)

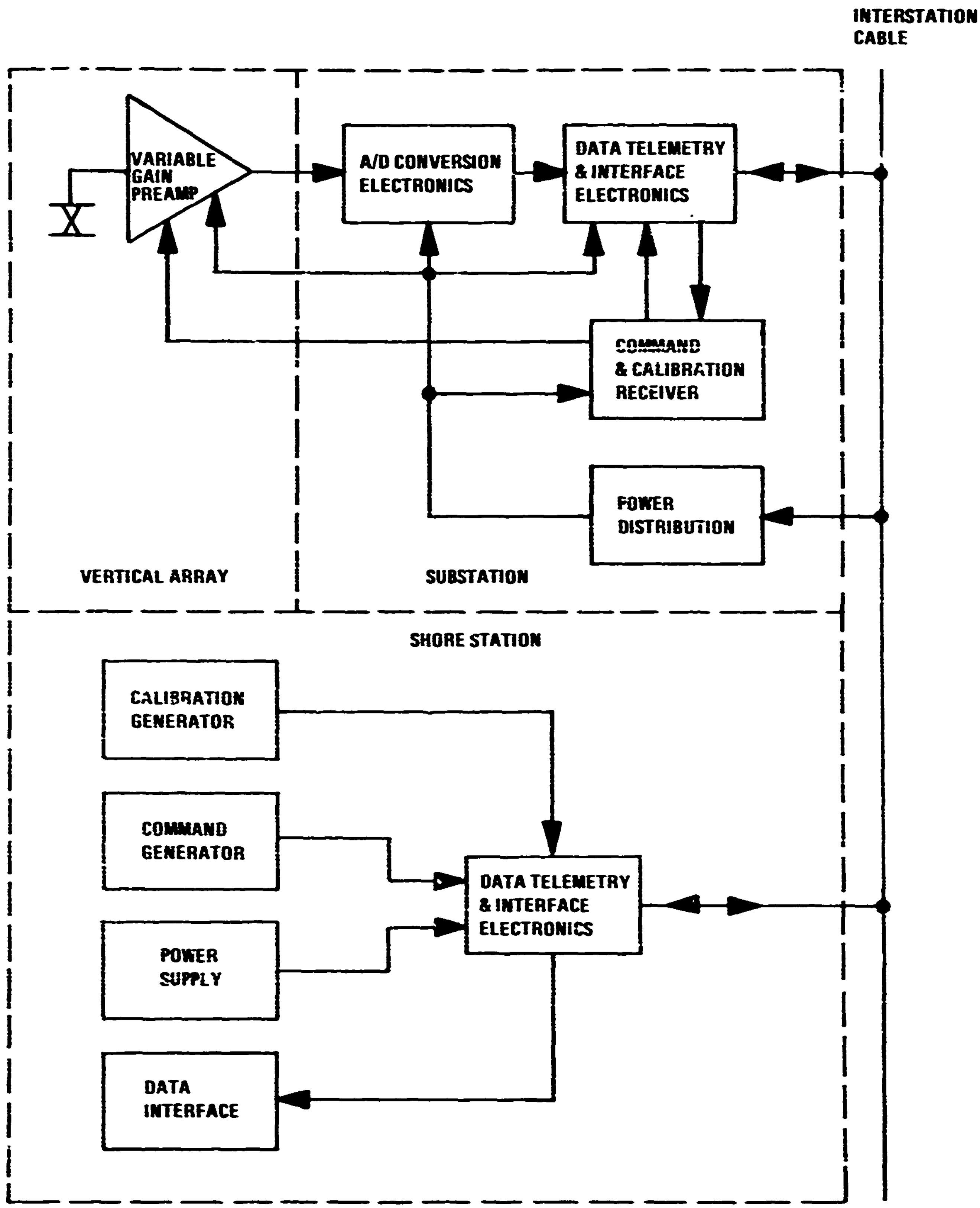

Figure 5-1. ATA Electronics Functional Block Diagram

(U) The command console will select the hydrophones and be able to control the gain of each hydrophone preamplifier, providing four gain settings in 12-dB steps. All gain change commands will be accompanied by a calibration signal which will permit gain checks before and after the gain change. Commands will also be available to turn any half substation off in the event its electronics malfunctions in a manner that interferes with data telemetry from other substations. Finally, since the most distant substation normally generates the multiplexing timing signals for the entire array, commands will be able to turn on that function in an alternate substation in the event of a catastrophic failure of the most distant one.

(U) All of the underwater electronics will be powered from shore by means of direct current flowing down the cable and returning at seawater potential. DC power will be taken off the line by means of zeners in series with the line. The zeners will provide a regulated low impedance voltage source, and will not attenuate, or be affected by, commands and data flowing along the same line and through the zener.

(U) 5.2 System Power Distribution

(U) Power for the system is supplied via the cable from the shore station. Power for each of the redundant electronics packages in the substation is extracted in the line interface circuitry of the acoustic substation across a zener diode which is in series with the coaxial center conductor. In addition, power for the data interface circuitry or repeater is extracted independently by means of two other diodes.

(U) All devices on the line are powered in series. The same current flows through each device, so cable current must be only as much as is required by the worst case signal device. The data interface circuitry, when driving the SDC cable, requires 120 milliamperes peak. We have added a 30-milliampere margin for safety and set line current at 150 milliamperes.

(U) The total line voltage applied to the system at the shore station will be the sum of all voltage drops along the cable. These add up as follows:

(U)

	Basic System	Recommended System	Expanded System
SDC Cable IR Drop	12 Vdc	12 Vdc	12 Vdc
Interstation Cable IR Drop	4 Vdc	4 Vdc	16 Vdc
Substation Electronics	96 Vdc	96 Vdc	192 Vdc
Repeaters and Line Driver	23 Vdc	23 Vdc	27 Vdc
Total	135 Vdc	135 Vdc	247 Vdc

(U) 5.3 System Control

(U) The operation of the Acoustic Test Array will be controlled from shore at a shore station. The operator at the shore station can select any ten data sources for telemetry. This selection is made from 32 sensors (20 acoustic/4 depth/8 tilt) in the Basic System, 52 in the Recommended System (40/14/8), or from 104 sensors (80/8/16) in the expanded System. In addition to the choice of sensors, the operator controls the gain of each hydrophone's preamplifier in four steps, selects the "master" station, turns stations on and off, and monitors their operation. System vertical array deployment is also controlled from shore.

(U) The shore control panel is designed to provide system control and to display system status based on a history of commands sent. Storage of command history is accomplished with mimimum space and cost by integrated circuit random access memories. The control panel will represent one vertical array, as shown in Figure 5-2. The substation being controlled is represented by the large rectangle at the bottom left corner of the control panel. Each smaller rectangle above it will represent a single hydrophone in that array. The hydrophones are divided into two groups to represent control by each of the two redundant sets of electronics in the substation. Any single array may be selected for control and status display by setting the thumbwheel switch labeled ADDRESS to the desired substation number. A pictorial representation of the activated hydrophones in the array are represented above the control panel by lights.

(U) The commands for the first electronics package in each substation, "Substation Electronics A", are set up by the thumbwheel and illuminated push-push type switches to the left

(U)

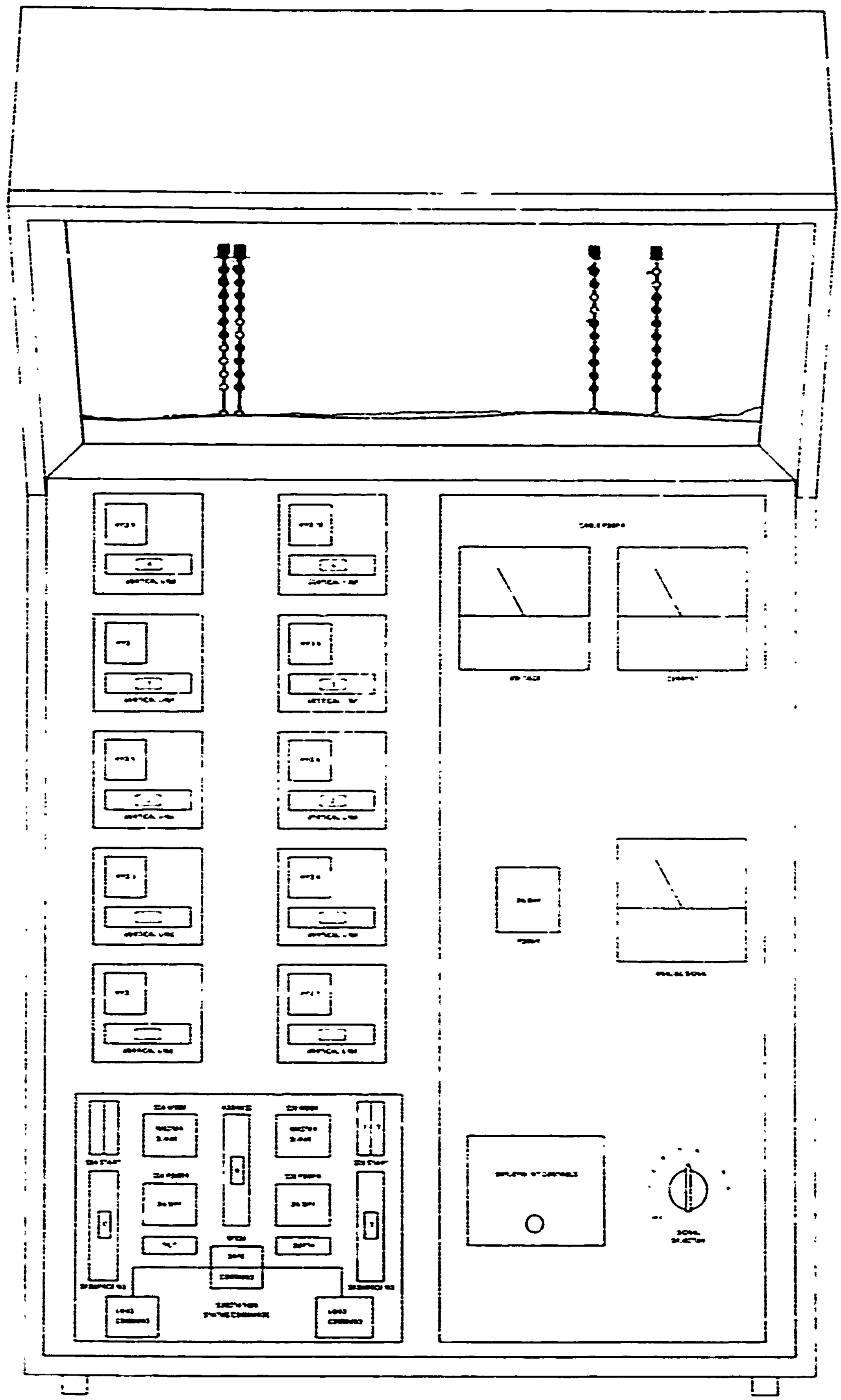

Figure 5-2. Shore Station Control Panel

(U) of the ADDRESS switch, while controls for "Substation Electronics B" are located to the right. These are marked SSA and SSB respectively. The MODE switch is used to turn on the MASTER or "end" station electronics which generate the telemetry Barker code and master clock signals in the most distant substation, and to set all other substations to the SLAVE mode so that they track the MASTER station and synchronize their data telemetry circuits with it. The START SEQUENCE NO. labels a thumbwheel switch and a numerical readout. The switch selects one of the 10 data slots to telemeter the first data word from Substation A (SSA).

(U) Data from remaining sensors selected in SSA will be telemetered in alternate data slots thereafter. For example, when telemetering acoustic data from ten hydrophones in one vertical array, SSA is set to START SEQUENCE NO. 1 and SSB to NO. 2 and data from H1 through H10 is telemetered in data slots 1 through 10, respectively. Use of alternate data slots allows enough time to accomplish analog-to-digital and sample-and-hold operations in each half of the substation. The numerical readout above the thumbwheel switch displays the most recent data slot command transmitted for that substation. In case no data is being transmitted, the substation START SEQUENCE NO. is set to zero. The eleventh data slot is mentioned in another paragraph and is provided to allow for arbitrary selection of any ten sensors.

(U) Each substation is divided into two redundant sections, and each section monitors alternate hydrophones in the vertical array. In the Basic array, one half of the substation monitors three hydrophones, while the other half monitors only two. In the ten hydrophone array, both halves monitor five hydrophones. Each half contains complete electronics, including an analog-to-digital converter. These converters are limited in conversion rate to 5,000 conversions per second or less, with power consumption dropping rapidly as rate decreases. The required data rate from each is 600 samples per second. To multiplex data from eleven sources, data slots 12 x 600 = 7,200 words per second (Section 5.4). The 7,200 rate is too high for a single A/D converter but this is no problem if data is alternated between two converters, permitting each converter to operate at half speed. Now since it is desired to transmit data from up to ten arbitrarily selected hydrophones, it will be noted that eleven data slots are required for certain combinations. For example, to transmit data from three hydrophones in each of three substation halves, it is necessary to use telemetry slots 1, 3

(U) and 5 for the first substation, 2, 4 and 6 for the second substation, and 7, 9 and 11 for the third substation. Other combinations of ten sources requiring 11 data slots are 4+4+2, 4+3+3, 4+2+2+2, and 2+2+2+2+2. To sample the combination 4+3+3, within 11 data slots requires the on-shore operator to program the four sources into slots 2, 4, 6 and 8; then 1, 3 and 15; and 7, 9 and 11 for the other sets of three.

(U) At the bottom of the substation rectangle, three switches control the actual transmission of the commands. The MODE switch, when switched from SAFE to COMMAND condition, enables command transmission. The LOAD COMMAND loads all thumbwheel switch settings into the command transmission shift register and enables the TRANSMIT COMMAND button. Pressing the latter then initiates transmission of the 23-bit command (in the case of the basic system). The TRANSMIT COMMAND button is lighted in red until completion of the command transmission.

(U) On the right side of the control panel is the power-on switch for the array and two meters for monitoring dc line voltage and current. A third meter can monitor the dc levels of any of the 11 data telemetry channels. The deployment commands are also controlled by switches located for safety under the hinged cover plate.

(U) The substation commands will be implemented by audio frequency tone signals transmitted from shore along the coaxial cable. This tone can be transmitted simultaneously during data transmission since it is easily separated from the data pulses which are at a much higher frequency. The tone will be pulse code modulated in a manner very similar to that used in teletype communications. A start pulse announces the beginning of the asynchronous command and starts the command receiver clock in each substation. A series of bits follow the start pulse at a predetermined rate. The first four bits identify the substation to which the command word is addressed. The remainder of the bits in the command word are organized to minimize the decoding electronics required in each substation and thereby maximize underwater system reliability. This results in a somewhat longer command word. However, command speed is not considered to be as important as command reliability in this system.

(U) Command decoding electronics is minimized by giving each oit in the command word a single function wherever possible. Also, all variables to a given substation are included in each command word to eliminate secondary memory requirements normally used to store one type of command during receipt of another type.

(U) The command word organization for the Basic system will be as shown in Figure 5-3. A start pulse is followed by four substation address bits (for eight sets of substation electronics in four substations plus space substation address). Four bits then select hydrophones and sensors for data telemetry, and four more bits select the data slot in the multiplex scheme in which the first data source will transmit data. Seven bits then set up the gains of up to three hydrophone preamplifiers. Two bits are required for each preamplifier, and these bits are switched directly to the hydrophones via the vertical cable, superimposed on the conductor used for B-. The three sets of two bits each are preceded by a start bit for use by the individual gain command receivers at each of the hydrophones. After the gain command come two substation control bits, one to turn the substation off when necessary, and one to set it to the "Master Station" telemetry mode. Finally, a parity bit verifies command integrity. A 23-bit command, sent at the rate of 10 bits per second, will require a command transmission time of 2.3 seconds. The commands are transmitted in sequence for the two halves of the substation, for a total elapsed time of 4.6 seconds.

(U) In the Expanded system, the command word becomes 12 bits longer. One bit is added to the substation address code to provide for doubling the number of substations. Six bits are added to select five hydrophones instead of two. Four bits are added to select gains of two more preamplifiers. Two bits are added to the substation control word to allow for depth adjustment. Thus, total command word becomes 35 bits in length for the Expanded system.

(U) For the Recommended system, the same command word structure of 35 bits as in the command system is retained. This allows for system growth.

(U) 5.4 Data Transmission

(U) Data sources for this system will be analog, consisting principally of the hydrophone signals, with additional data available from sensors measuring hydrophone depth, array tilt

(U)

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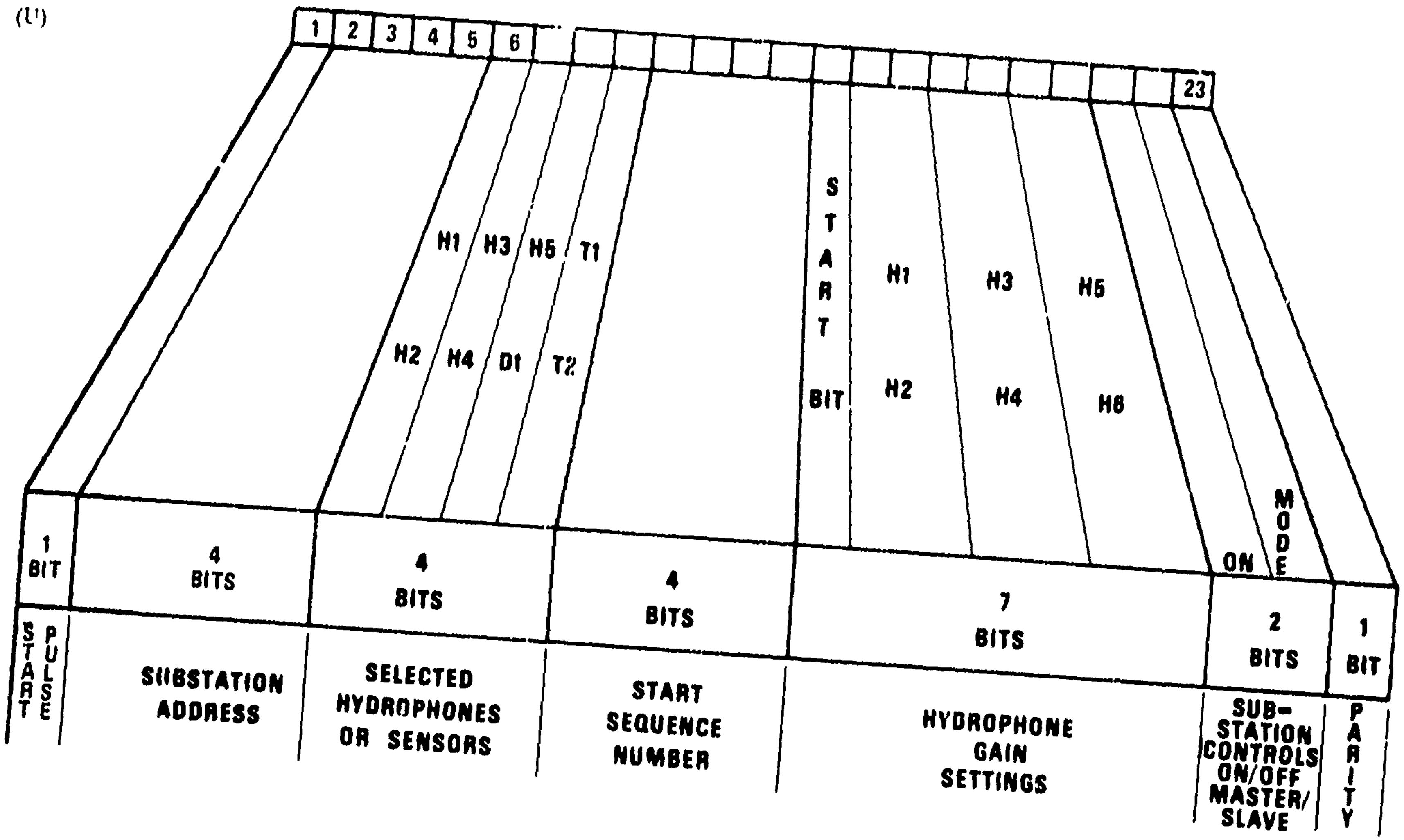


Figure 5-3. Command Word Organization

(U) and the presence of moisture inside the substation electronic and repeater housings. Data desired from the hydrophones and the sensors will be converted from analog to digital by the A/D converter and multiplexed onto the coaxial cable.

(U) 5.4.1 Data Multiplexing Technique

(C) Each data sample will be converted to a 12-bit digital word plus one bit of parity. Each data source will be sampled 600 times per second. Up to eleven data sources will be transmitted to shore simultaneously. The data will be transmitted in groups of eleven 13-bit words, preceded by a sychronizing or Barker code word of 11 bits and 2 moisture alarm bits (Figure 5-4). Thus, data rate will be 13 x 600 x (11 + 1) = 93.600 kHz.

(U) The Barker code, a pseudo-random word of 11 bits, will be generated by the most distant substation or "master station" and will be transmitted shoreward along the cable. Each succeeding station will receive and identify the Barker code and retransmit it shoreward while at the same time synchronizing a 93.600 kHz clock within the substation to the line. Clock synchronization will be accomplished by means of a phase locked loop. Two bits after each 11-bit Barker code, a word counter will be reset and thereafter the word counter will be incremented every thirteen bits. Each substation will keep track of the word count in this manner and will be able to insert data onto the line in any commanded word slot. The desired data sequence will be preset by the control signals from shore.

(U) At the shore station, the data receiver will have similar circuits. A phase locked loop will synchronize a clock to the 93.600 kHz data stream, and a Barker code detector will synchronize the word counter. Each data word will then be separated out of the data stream and applied to one of ten output wires for signal processing.

(U) 5.4.2 Barker Code Synchronization Circuitry

(U) The 11-bit sync or Barker code will be transmitted at the beginning of each 156-bit message by the appointed master station. As can be seen from the block diagram, Figure 5-5, the data stream is continually routed through a 13-bit shift register. Connected to the output of this register is the Barker code detector, a 11-bit AND gate, that is continually

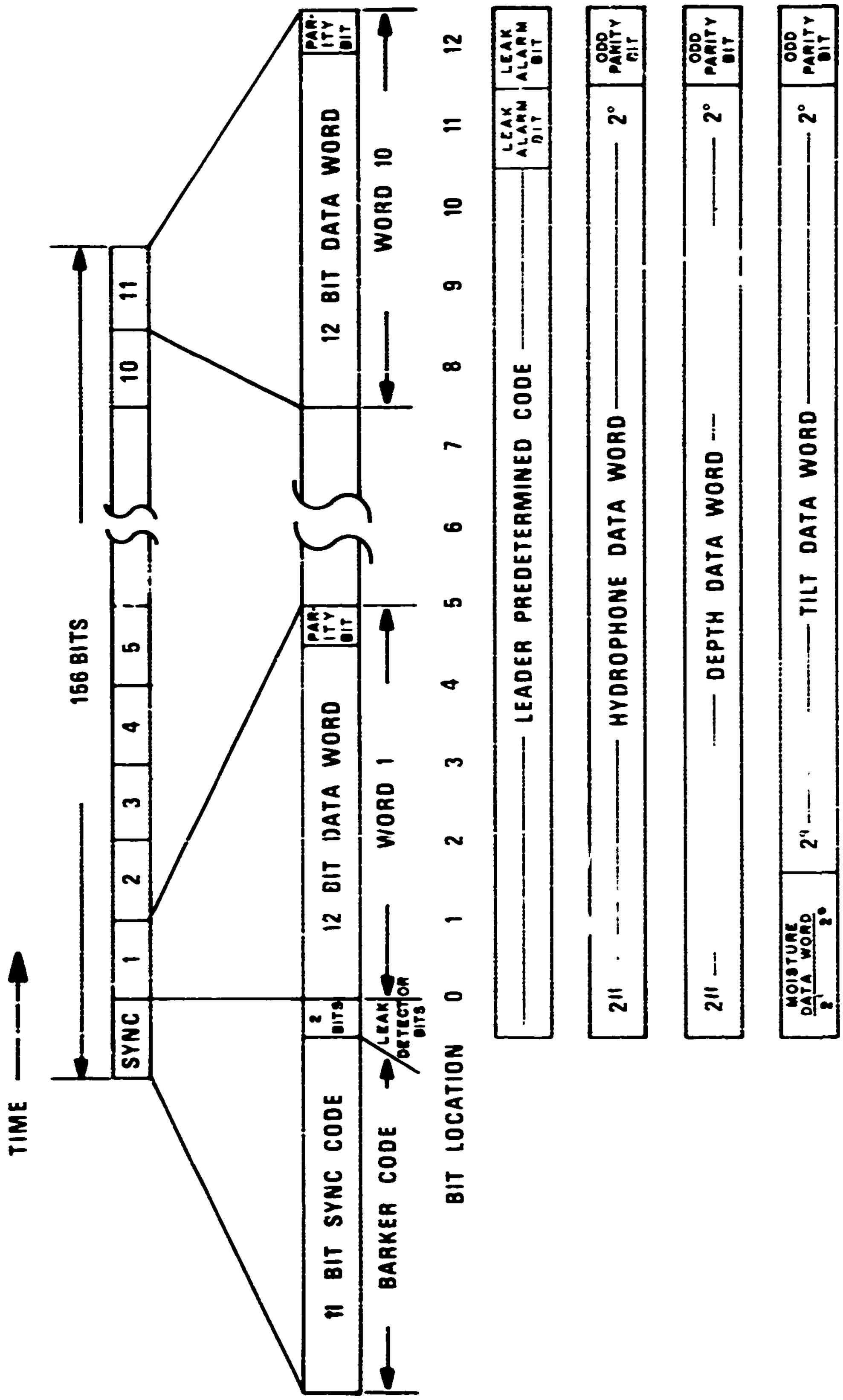
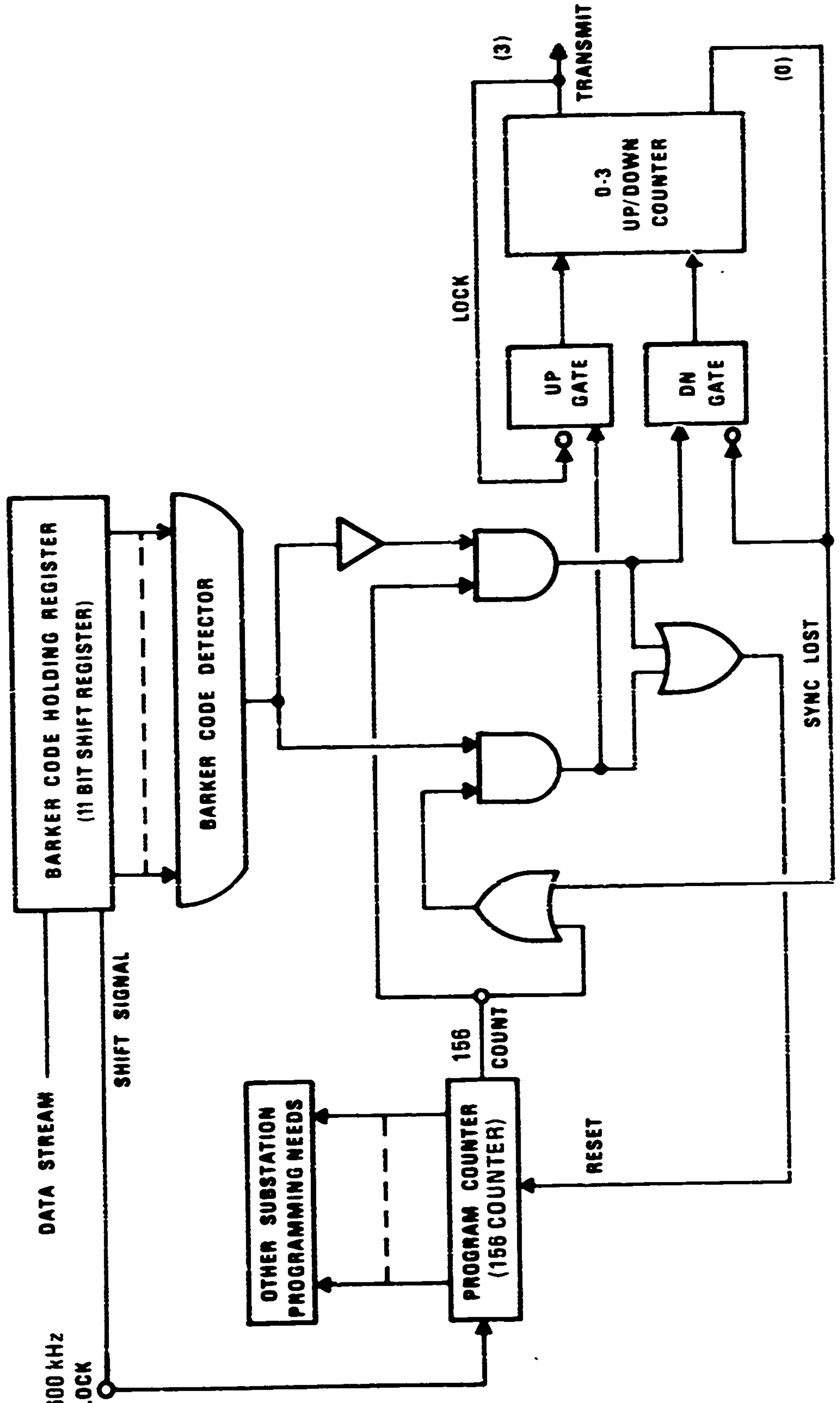


Figure 5-4. Data Multiplexing Organization

(U)



(U) *Figure 5-5. Sync or Barker Code Detector*

(U) searching for the Barker code. As each Barker code is detected, a sync pulse resets the 156-bit counter. If the system is operating correctly and no noise has disturbed the data stream, each Barker code should coincide with the 156-count window provided by the program counter. As shown in the diagram, these two signals "block sync" and "count 156" are ANDed together to form one path for resetting the program counter. The other path for resetting the counter is formed by the AND gate whose inputs are "count 156" and the absence of a Barker code. These two signals are also used to drive the inputs to the 0-3 up/down counter. A Barker code at count 156 causes the counter to count up by one count. The absence of a Barker code at count 156 causes the counter to count down by one count. The inhibits shown on the input gates of the up/down counter keep the counter from recycling. The 0 output of the up/down counter feeds into the OR gate controlling the Barker code true AND gate. Should sufficient sync codes be missed to cause the up/down counter to reach 0, a sync lost will be declared. This places a continuous input to the OR gate feeding the Barker code true AND gate. This, in effect, removes the 156-count window and allows the Barker code detector to search continually. When sufficient Barker codes have been detected to cause the up/down counter to count to three, lock will be declared, the transmitter inhibitor will be removed, and a message will be placed in the data stream.

(U) In normal operation, if the Barker code sync signal is arriving in coincidence with the 156-count window as it should be, the up/down counter will stay in the three state and allow data to be transmitted continually in the time slot allotted to that substation. However, if a Barker code sync should not arrive in coincidence with the 156-window, the up/down counter would count back to 2. This would place an inhibitor on the transmitter and prevent a message from being sent during this block of data. However, the 156 signal is routed to the program counter to keep it in step as though a Barker code has been received. If during the next data block time a Barker code sync signal is received, the up/down counter will return to 3 and a block of data will be transmitted. If two sync signals are missed, it will require receipt of two good Barker codes to reactivate the transmitter. Should the up/down counter reach (0), a sync lost condition would be declared, and the requirement that the Barker code coincide with the 156-count window would be removed. The Barker code detector would then start searching for any Barker code in the data. If such a code were located, the programmer

(U) would reset to (0) and the up/down counter advanced to 1. If at count 156 a second sync signal was detected, the counter would advance to 2 and so on until lock was again declared. If a sync had not been detected, the up/down counter would, of course, have backed down to (0) and started searching again.

(U) 5.4.3 Substation-To-Cable Interface Circuitry

(U) Each substation extracts power and commands from the interstation cable, monitors data passing through the substation on the cable, and multiplexes data from local sources onto the cable. Figure 5-6 shows the circuitry that accomplishes these functions.

(U) Power is extracted from the line by the zener diode Z1. A breaker and a diode (D3) protect the cable from short circuits and shorts to seawater occurring in the substation and vertical array electronics. The low impedance of the zener bypasses data and commands around the supply.

(U) Commands are tapped from the line by a capacitive voltage divider, C1-C2, followed by a low pass filter. A detector circuit with a high input impedance allows use of low value capacitors that do not cause any increase in line attenuation at the command tone frequency. With this technique, 90 percent or more of the command signal level on the line can be tapped off at each substation.

(U) Data pulses coming in from the seaward direction are tapped off the line by a transformer (T2), amplified and shaped, and re-inserted onto the line with a line driver. The low side of the input transformer T2 is grounded at the data frequencies by the command signal voltage divider. The output of the line driver is isolated from ground by the primary inductance of the data monitor transformer, T1. The data circuitry is self-powered b_ he forward drop across diodes D1 and D2.

(U) The circuitry shown in Figure 5-6 is simplified in that it shows the inputs and outputs for only one of the two redundant substation electronics packages. A second zener and associated circuits provide power for the other package, and additional windings on the transformers T1 and T2 provide data monitor and output points. A second voltage divider in parallel with the first then provides a redundant command tap-off point.

(U)

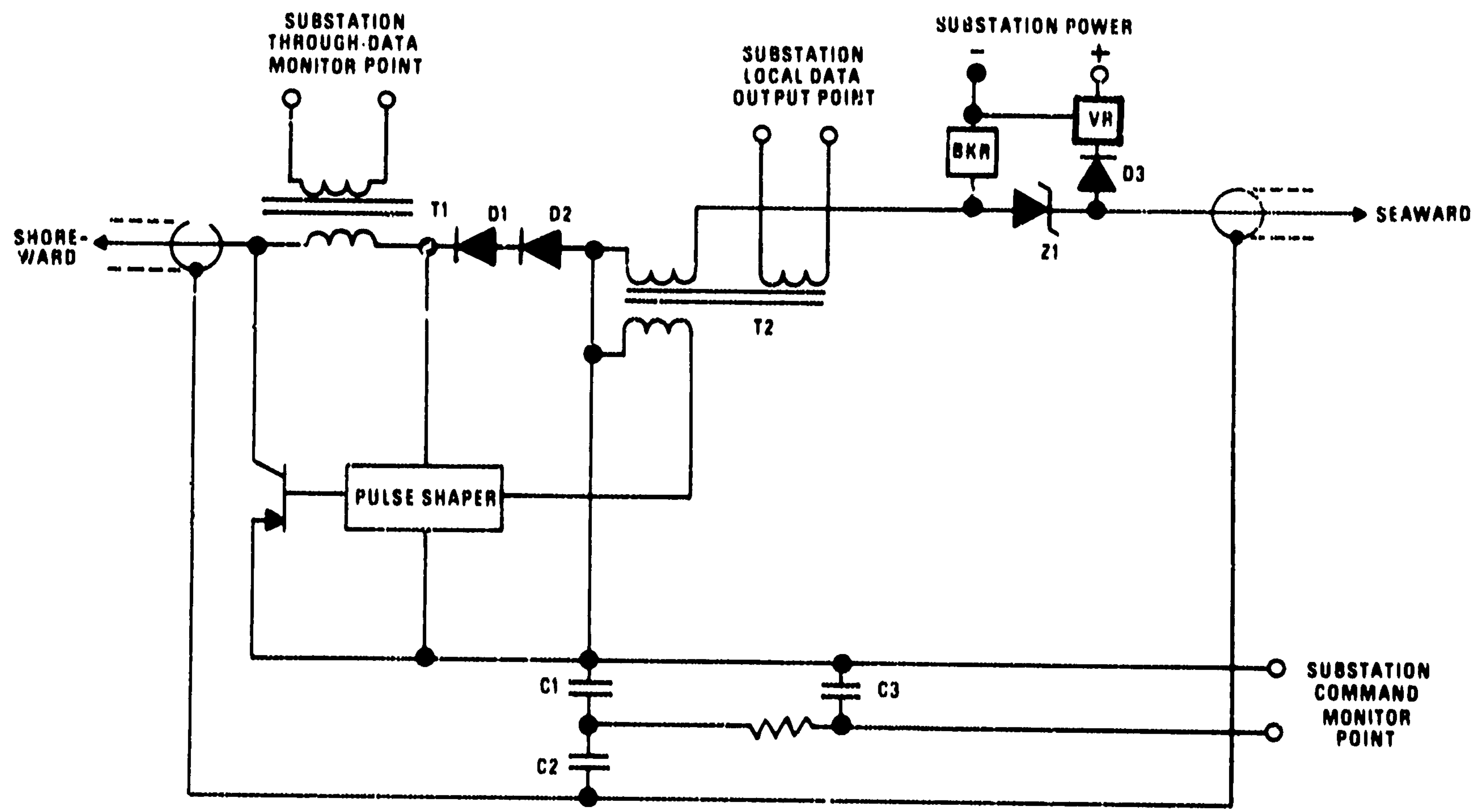


Figure 5-6. Simplified Substation Line Interface Circuit

(U) 5.4.4 Shore Station Telemetry Receiver

(U) The output of the data link as seen by the shore station will be a 93.600 kilobit/second data stream. The shore station electronics in part consist of a demultiplexer that processes this data stream to the point where signal processing can begin. The first step is to establish bit and block synchronization. This will be done identically to the manner in which synchronization is accomplished in each substation; i.e., by phase locking a clock to the data stream and by counting down this clock by 156 and comparing and synchronizing this pulse stream with the sync pulse stream obtained from the data stream and a 12-bit block sync register and gate.

(U) This approach, as in the substation, also provides a gate signal for each 12-bit block of data, i.e., for each word, and at the same time provides a 4-bit address identifying the word. This 4-bit address is inherently in the count by the 0 to 11 counter.

(U) The demultiplexer will consist of two 16-bit registers which will be loaded and unloaded alternately depending upon whether the count by the 0 to 11 counter is presently on an odd or even word. As the count switches from odd to even the address stored in the count by the 0 to 11 counter will be transferred to the front 4 bits of the output register thus forming a 16-bit word, i.e., 12 bits from the data stream and a 4-bit address identifying the data word. The data stream flows into one register or the other at all times. If digital data is required as an output to a computer, the use of two registers will allow it to take the data on a low priority interrupt basis.

(U) Each time a register is filled, the 12 bits can be converted to an analog signal, and the 4 address bits will be used to gate on the 11 registers. These 11 circuits will then provide the outputs from the 10 multiplexed sensors.

(U) 5.4.5 Data Telemetry Reliability Considerations

(U) The Acoustic Test Array design contains many redundant features to maximize its reliability. In general, design is such that failure of any single component other than the cable itself will not cause a failure of the array. In the case of the interstation cable, even

(U) a failure of the outer jacket will not cause system failure, since the outer conducter is at or near seawater potential. The loss of a single hydrophone or its preamplifier will only slightly degrade the system. The electronics for each vertical array are fully redundant. Two redundant electronics packages in each substation are housed in separate cavities with independent seals. Each electronic section telemeters the data from alternate hydrophones. Each contains an A/D converter, and for command purposes, each is treated as an independent substation. Flooding of one of these cavities will not degrade the other half of the station, and will only result in loss of alternate hydrophones in that array.

(U) A circuit breaker will disconnect a flooded electronic section from the system, preventing it from prematurely terminating the dc power path to seawater ground. The circuit breaker is resettable from shore in the event a transient trips it. The circuit breaker for both cavities is located in a smaller third cavity, along with a data repeater circuit which provides the interface betw en the electronics and the cable. The repeater alone is capable of retransmitting all through-put data coming in from seaward substations towards shore, so that a failure of both redundant sections of the local substation will not cause a failure of data from any other substation. However, in the event that the third cavity leaks, it is equivalent to a cable failure at that point and data from more distant substations will be lost.

(U) All substations contain "master station" circuitry and can generate upon command, the data link master clock and sync or Barker code. This is an important feature since it precludes the failure mode in which the most distant substation could prevent transmission of data for the entire system. Similarly, there is an "off" mode of operation in each substation that prevents a component failure from causing generation of out-of-sync data or noise and thereby invalidates all other data on the line. The "off" mode will remove power from that substation cavity by tripping its circuit breaker.

(U) 5.5 Vertical Array Electronics

(U) The vertical array electronics shown in Figure 5-7 consists of the multi-gain preamplifiers located physically in each hydrophone and the A/D conversion electronics located in the substation.

(U) Each preamplifier will provide a dynamic range of 60 dB with four 12 dB gain steps which can be commanded from shore and which provide gains of 30, 42, 54, and 66 DB. Figure 5-8 shows the recommended gain settings as a function of the sound pressure level in the water. These gain settings will insure that the rms value of the signal will occupy 6 to 10 bits of the 12-bit A/D converter in the substation. In addition these recommended settings provide for 12 dB of overlap between gain settings.

(U) The critical design parameter of the preamplifier is its input impedance, since this parameter sets both the low frequency response and the self-noise of the system. The hydrophone electrically looks like a capacitance and forms a one pole high pass filter with the input impedance of the preamplifier. Therefore, if the lowest frequency that the preamp should process is 5 Hz, then the following equation must hold true:

$$\frac{1}{2\pi RC} \le 5$$

R = preamp input impedance
C = hydrophone capacitance

Of the hydrophones under consideration for this system, the minimum value of C is 1600 pF. Therefore,

$$R \ge \frac{1}{2\pi\,(5)\,(1600\times10^{-12})} = 20\ \mathrm{M\Omega}$$

from the above equation.

(C) Given that the minimum input impedance is 20 MΩ, then the maximum self-noise of the system rolls off at 6 dB/octave above 5 Hz with a maximum value below 5 Hz of

$$10 \log 4kTR = -125 \text{ dB re } 1\mathrm{V/Hz}^{1/2}$$

This self-noise is plotted in Figure 5-9, assuming a hydrophone sensitivity of -80 dB. Also shown for comparison purposes in Figure 5-9, is the Wenz data for the limits of prevailing noise (Reference 4) and the usual deep water traffic noise in an ocean environment. In calculating the self-noise of the preamp, it is also necessary to take into account the self-noise of

(U)

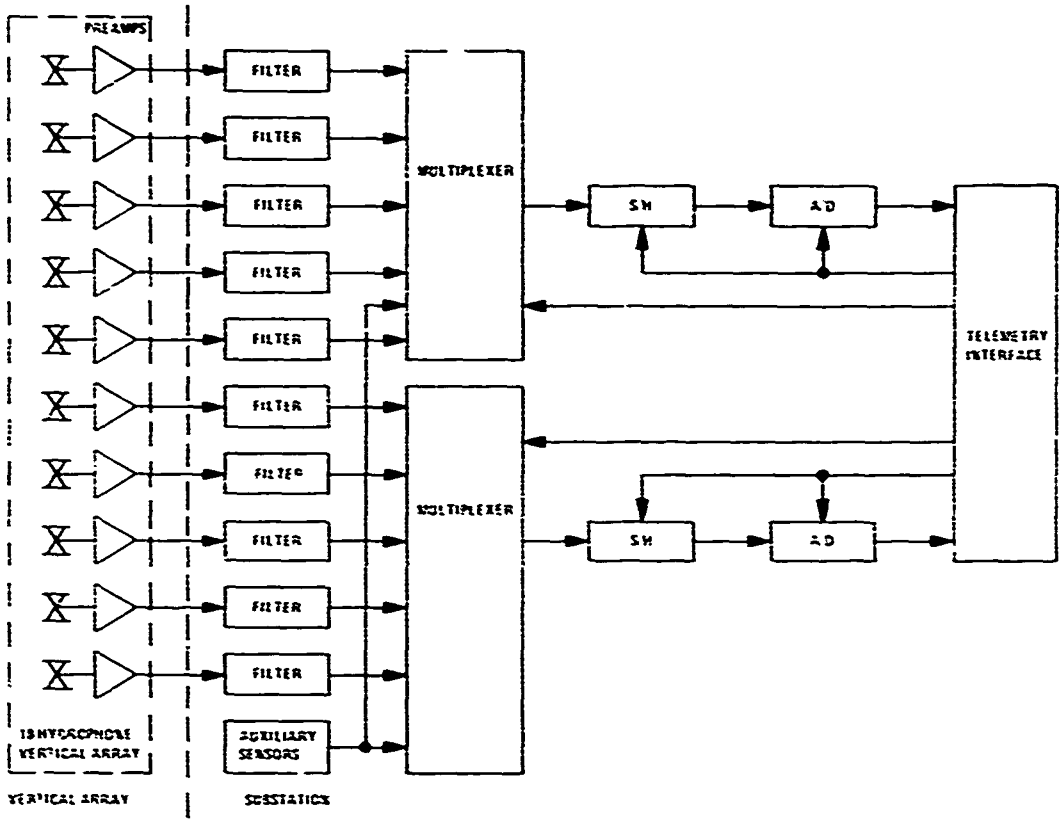


Figure 5-7. Vertical Array Electronics

(U)

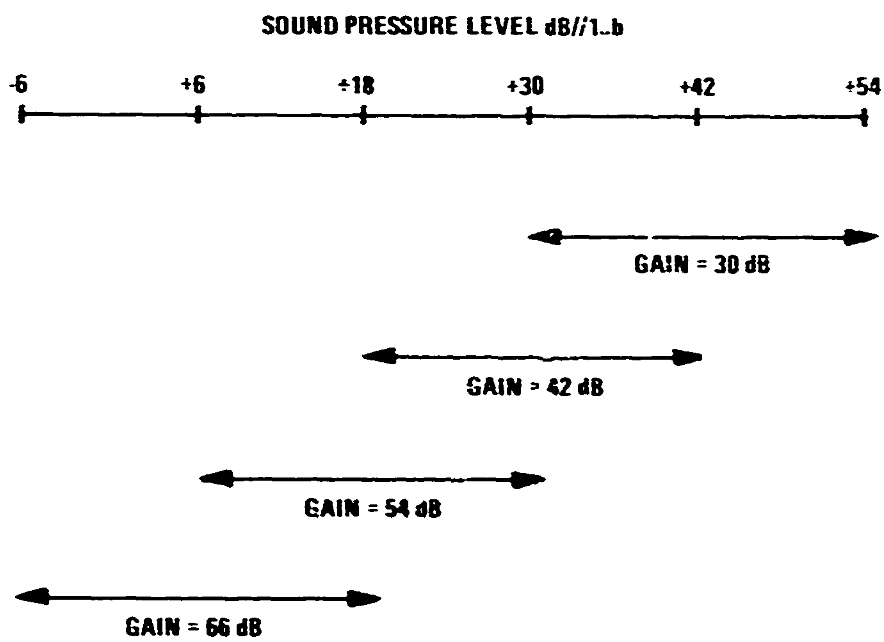
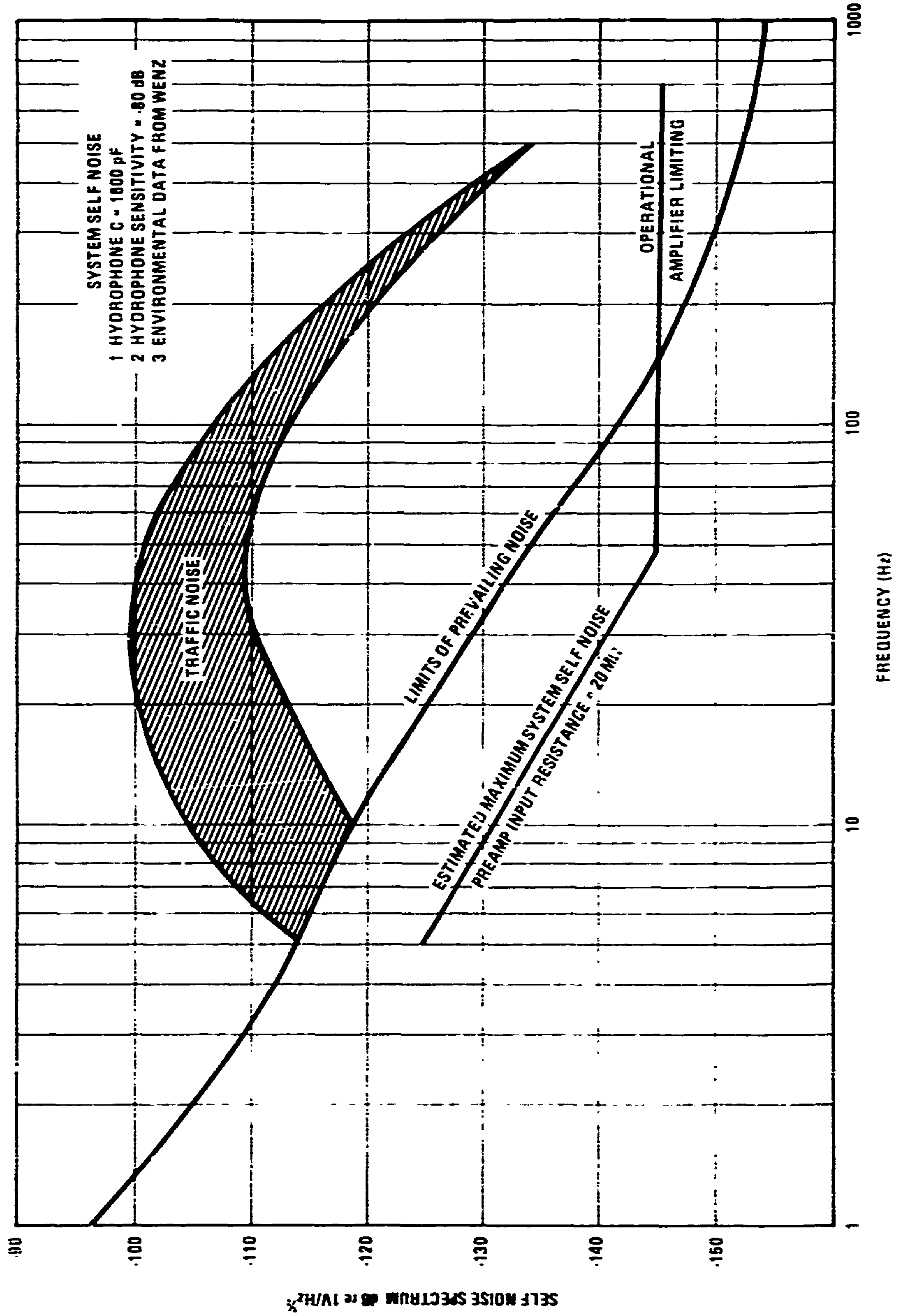


Figure 5-8. Preamplifier Gain Settings



(U)

Figure 5-9. System Self Noise

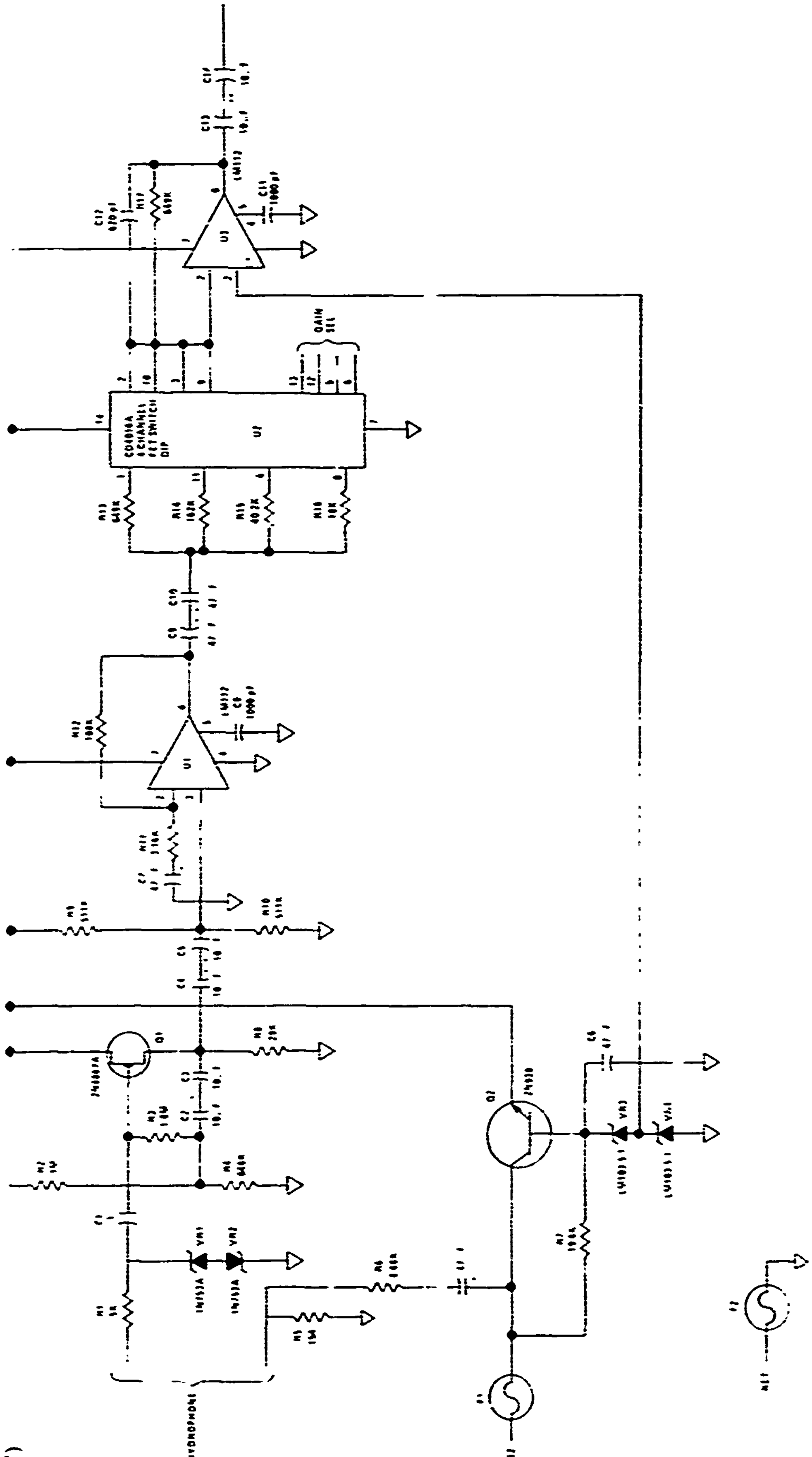
(C) the active devices in the system. In Figure 5-9, the self noise of the system is shown as bottoming out at about -145 dB re $1V/Hz^{1/2}$ which accounts for operational amplifier noise.

(U) Shown in Figure 5-10 is a proposed preamplifier design that will meet the characteristics outlined above. The preamplifier basically consists of a bootstrapped FET source follower input which is followed by a 30 dB fixed gain amplifier. This amplifier stage is in turn followed by a programmable gain stage which provides the four different gain steps using COS/MOS switching. It is estimated that the total power consumption of this preamplifier is in the order of 10 mW. Additional features of this design are that the preamp input has been protected from explosive-type shock by means of diodes VR1 and VR2 and that extremely good power supply filtering (Q2, C6, R7) has been provided since both calibration and command signals are superimposed on the B+ line. The power supply rejection at 100 Hz, the command frequency, is in excess of 50 dB. The preamplifier is also protected from electronic or sea-water shorts by means of the high reliability microfuses F1 and F2. These fuses will blow at 20 mA current which is 20 times the normal operating current of the preamp.

(C) The A/D conversion electronics in the substation consist of presampling filters (one for each hydrophone), a multiplexer, a sample and hold amplifier and a 12-bit A/D converter. The presampling filter is a 5-pole, 1 dB ripple Chebyschev filter with a break frequency of 200 Hz. This filter guarantees that aliasing, due to sampling at 600 Hz, will be in excess of 40 dB down up to the break frequency. Shown in Figure 5-11 is a proposed design for this filter which requires approximately 5 mW of power. Figure 5-12 is the computer calculated response of this filter.

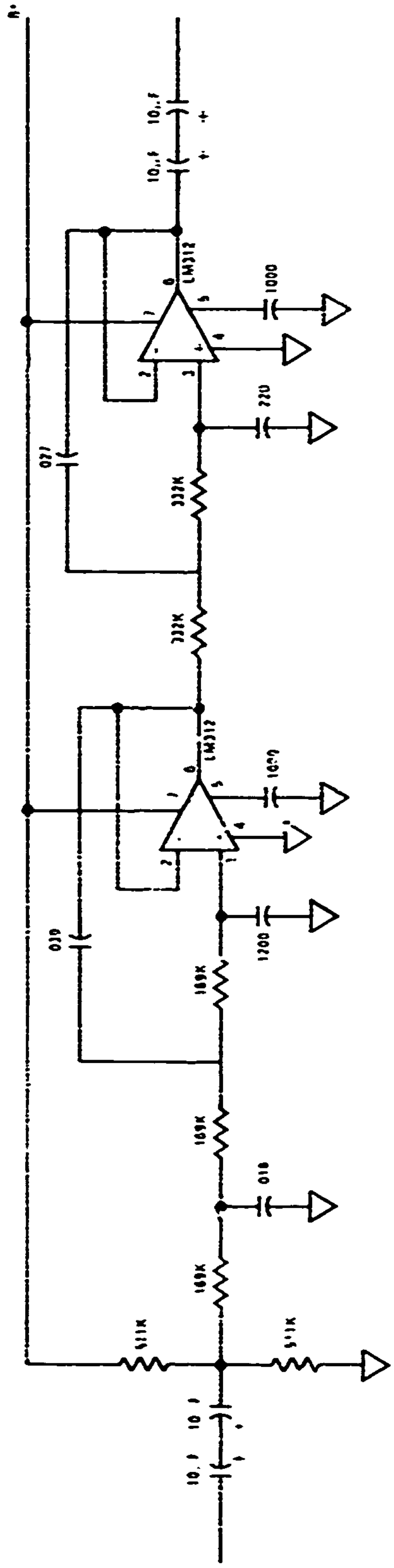
(U) The multiplexer and sample and hold amplifier make use of low power COS/MOS switches to select and sample the sensor that is to be A/D converted (either a hydrophone or a physical sensor). Shown in Figure 5-13 is a proposed design for this function which likewise requires in the order of 5 mW of power.

(C) The A/D converter that will be used is the Analog Devices ADC12QLJ-10 which is a low power, 12-bit A/D converter specifically designed for remote applications. The A/D converter requires a single-ended power supply and less than a 1/2 mW standby power. The A/D



(U)

Figure 5-10. ATA Hydrophone Electronics



(U) *Figure 5-11. 200 Hz Low Pass Filter*

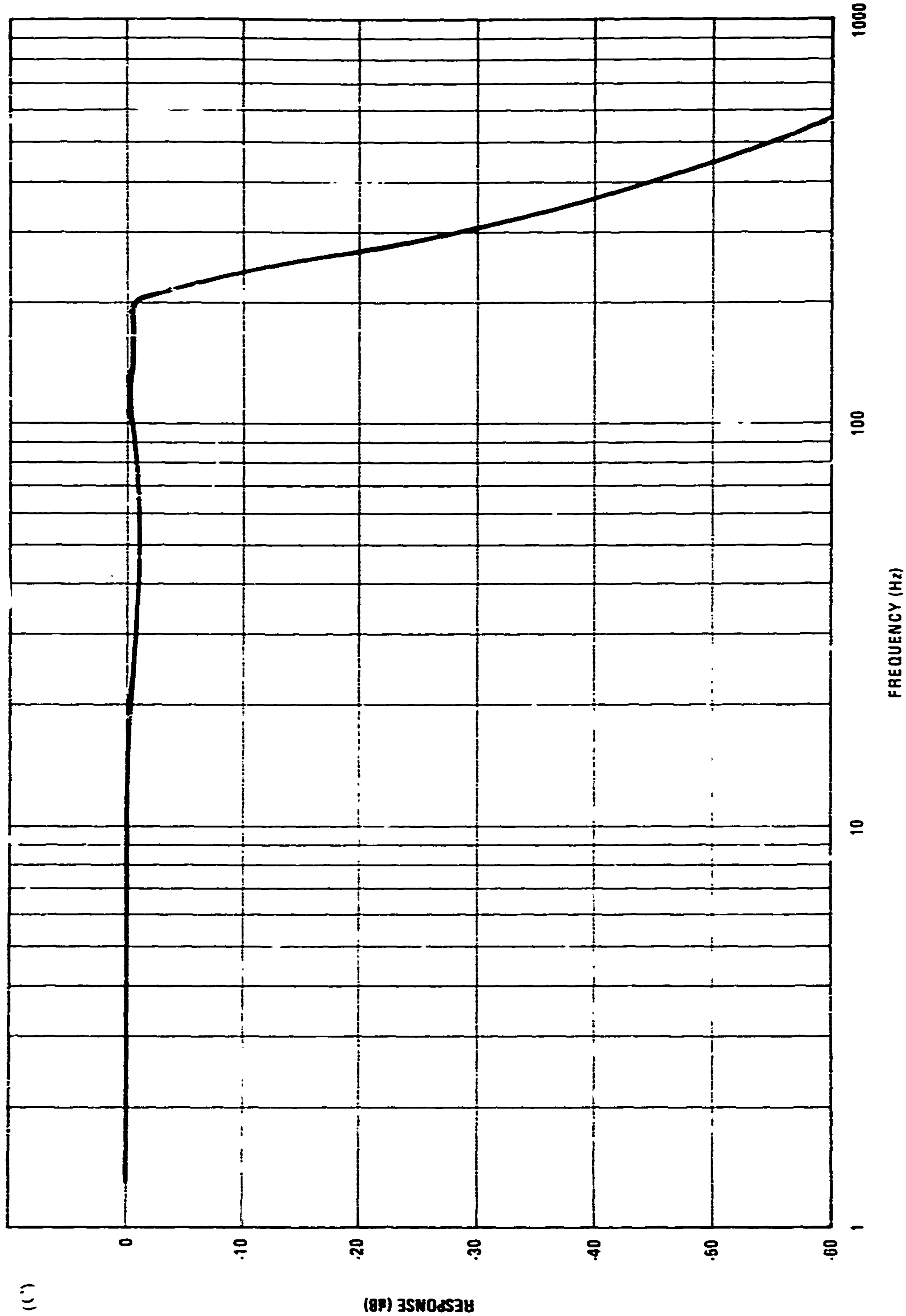


Figure 5-12. Low Pass Filter Response

(C)

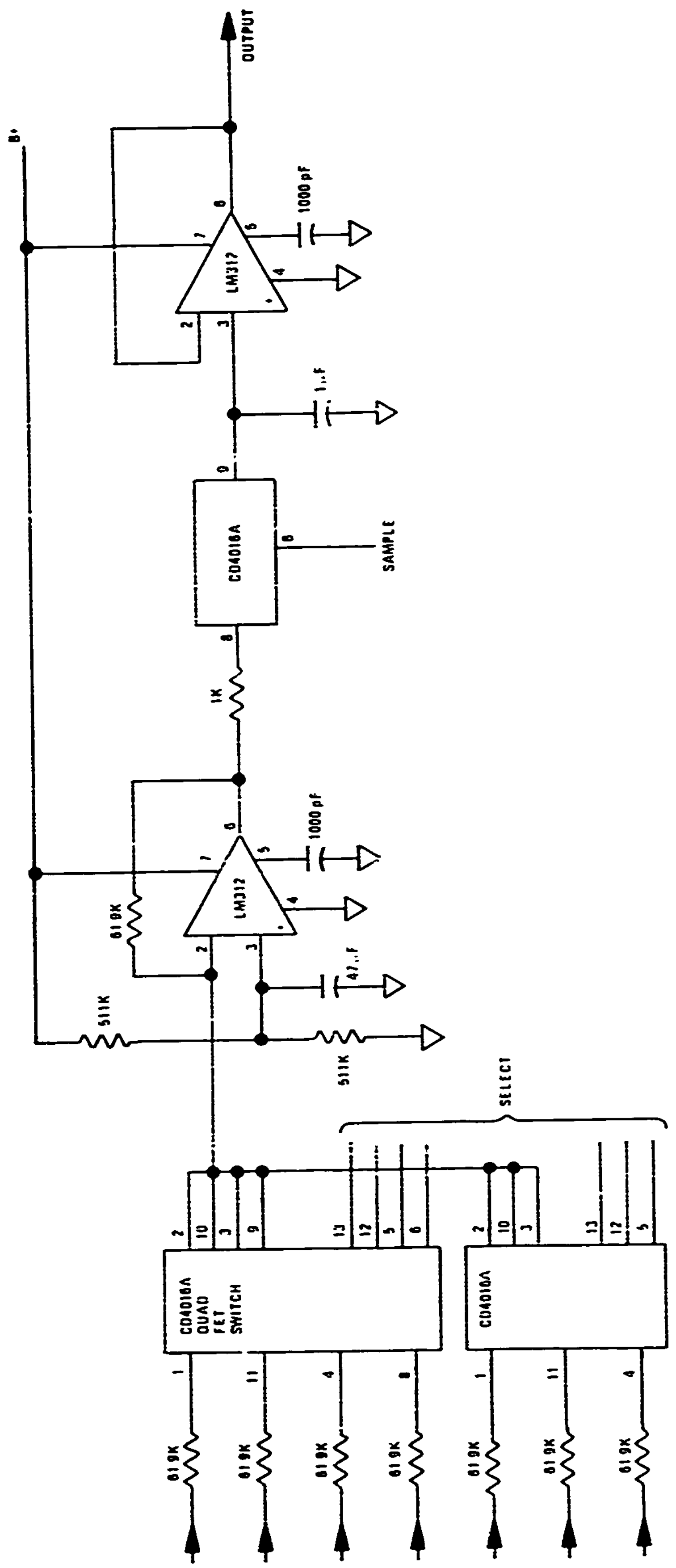


Figure 5-13. ATA Multiplexer/Sample & Hold

(U)

(C) converter is a COS/MOS device and hence, its maximum power consumption is a function of its conversion rate. Since each A/D converter can convert a maximum of five sensors at a 600 Hz/channel rate, then the fastest conversion rate is 3 kHz. At this conversion rate, the power consumption is about 175 mW.

(U) The interface of the vertical array electronics to the telemetry system has been designed to use a minimum of hardware. When the data repeater wants data to insert on the inter-station cable, it will supply a multiplexer address to the vertical array electronics to select the desired sensor and an A/D convert order. Upon completion of the conversion, the repeater will accept the data and serially insert it into the cable. In this manner, complex timing and data buffering have been avoided.

(U) 5.6 Calibration Techniques

(U) The system will have the ability to be calibrated from shore. The operator can command any substation into the calibration mode, in which case every hydrophone in a selected vertical array will receive any tone sent from shore. The calibration signal is inserted in series with each hydrophone, thereby testing the entire hydrophone channel including the electrical integrity of the hydrophone itself. When calibrating the system, a range of calibration frequencies and levels will be available which will provide the ability to test the system throughout the operating band and dynamic range. In this manner graceful degradation as well as catastrophic failure can be determined.

(U) Calibration before and after any change of gain setting of any hydrophone will be an operational procedure requirement.

(U) 5.7 Auxiliary Sensors

(U) Each vertical array will contain a depth sensor and a pair of pendulum type tilt sensors located in orthogonal planes. The output of each of these sensors will be treated in a manner similar to hydrophones. In the event that auxiliary sensor data is required on shore, the substation can be commanded to 12-bit A/D convert any sensor. The depth sensor, which is located in the substation, will be useful mainly during deployment in order to equalize the depth of all hydrophones. The tilt sensors, which are located in the area of the lowest

(U) hydrophone (where the angle of tilt due to a catenary in the vertical array is greatest), will be useful in confirming erection of the array and in monitoring the array tilt due to water currents.

(U) 5.8 Array Hydrodynamics

(U) 5.8.1 Horizontal Drag Forces

(U) Assuming that the maximum current velocity which the array would experience at its operating depth is 0.10 knot, the total horizontal drag force across the array is calculated to be less than 3 1/2 pounds. See Figure 5-14 for the mechanical model. This tiny force will be spread out along the full length of the array while the vertical forces on the array include a 50 pound cable minimum tension at the lower end and a 200 pound nominal line tension at the float. The horizontal forces can be considered negligible so that the array will maintain an almost perfectly vertical, straight configuration.

(U) 5.8.2 Cable Natural Frequencies

(U) In order to predict the susceptibility of the vertical array to noise-generating cable oscillations we must determine the most probable natural frequencies which our array will have. The array was assumed to approximate a completely flexible, slightly damped, vibrating cable of uniform mass restrained at both ends. The classical vibrating string equation defines the natural frequency of such a cable as:

$$f_A = \frac{1}{2\ell}\sqrt{\frac{Tg}{w}}$$

where:

f_A = natural frequency (Hz)

$2\ell = \lambda$ = wave length (ft)

T = cable tension (lb)

w = cable weight per length (lb/ft)

$g = 32.2\ \text{ft/s}^2$.

(U)

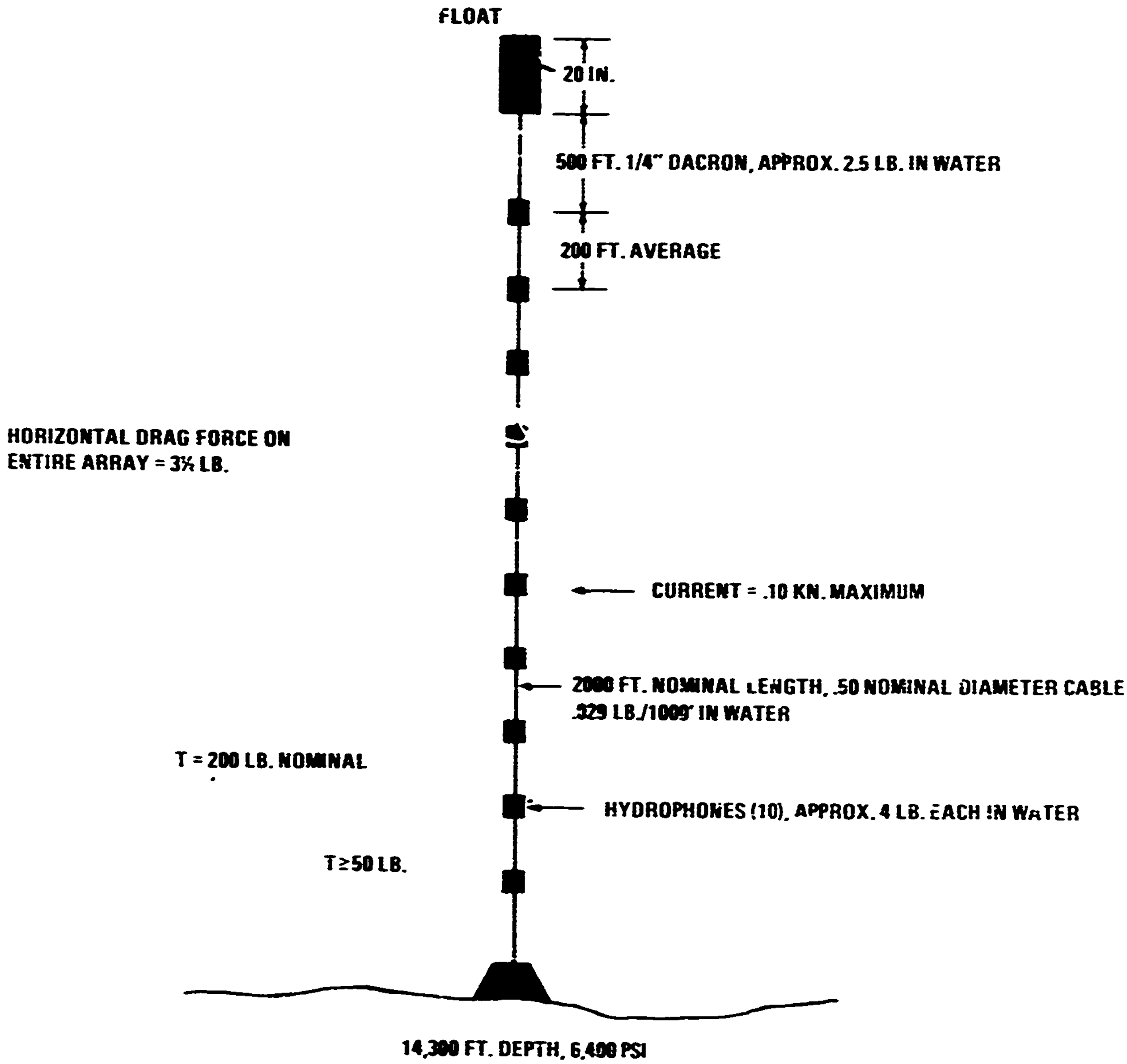


Figure 5-14. ATA Mechanical Analysis Model

(U) In analyzing the array vibration, we consider the 0.25 inch diameter dacron line separately from the 0.50 inch diameter hydrophone cable. While a vibrating flexible cable has an infinite number of natural frequencies, it is possible to establish a range of natural frequencies which our specific cable assembly is most likely to experience.

(U) The hydrophone cable has its lowest natural frequency when its wave length is at a maximum, that is, equal to twice its 2000 foot nominal length. Figure 5-15 illustrates this condition where f_n equals approximately .17 Hz. The fundamental natural frequency when the hydrophones form vibration nodes so that the wave length equals the 200 foot average spacing between hydrophones, is approximately 1.7 Hz, if the hydrophone spacing were equal and they were motionless, true nodal points.

(U) The lowest natural frequency which the dacron line can experience is established by its 500 feet length which limits its maximum wave length. Figure 5-15 illustrates this as 1.03 Hz.

(U) 5.8.3 Cable Flow-Induced Frequencies

(U) We can expect the worst cable vibrations to occur where the frequencies of flow-induced vibrations coincide with easily induced natural frequencies.

(U) The primary cause of the underwater cable oscillations ("cable strumming") is the formation, over certain Reynolds number ranges, of cable wake vortices shedding alternately from each side of the cable. These periodic vortices cause an increase in fluid velocity at their boundary, causing a drop in pressure which results in transverse forces acting periodically on alternate water velocities ranging from 0.04 to 100 knots indicated that the flow-induced oscillations occur in a range of Reynolds numbers from 40 to 100,000, and are most stable below 300.

(U) The maximum Reynolds number for this cable is 274 considering the kinematic viscosity (ν) to be at standard sea water temperature of 15°C. Figure 5-16 illustrates this relationship and also the Strouhal number as a function of the Reynolds number.

(U)

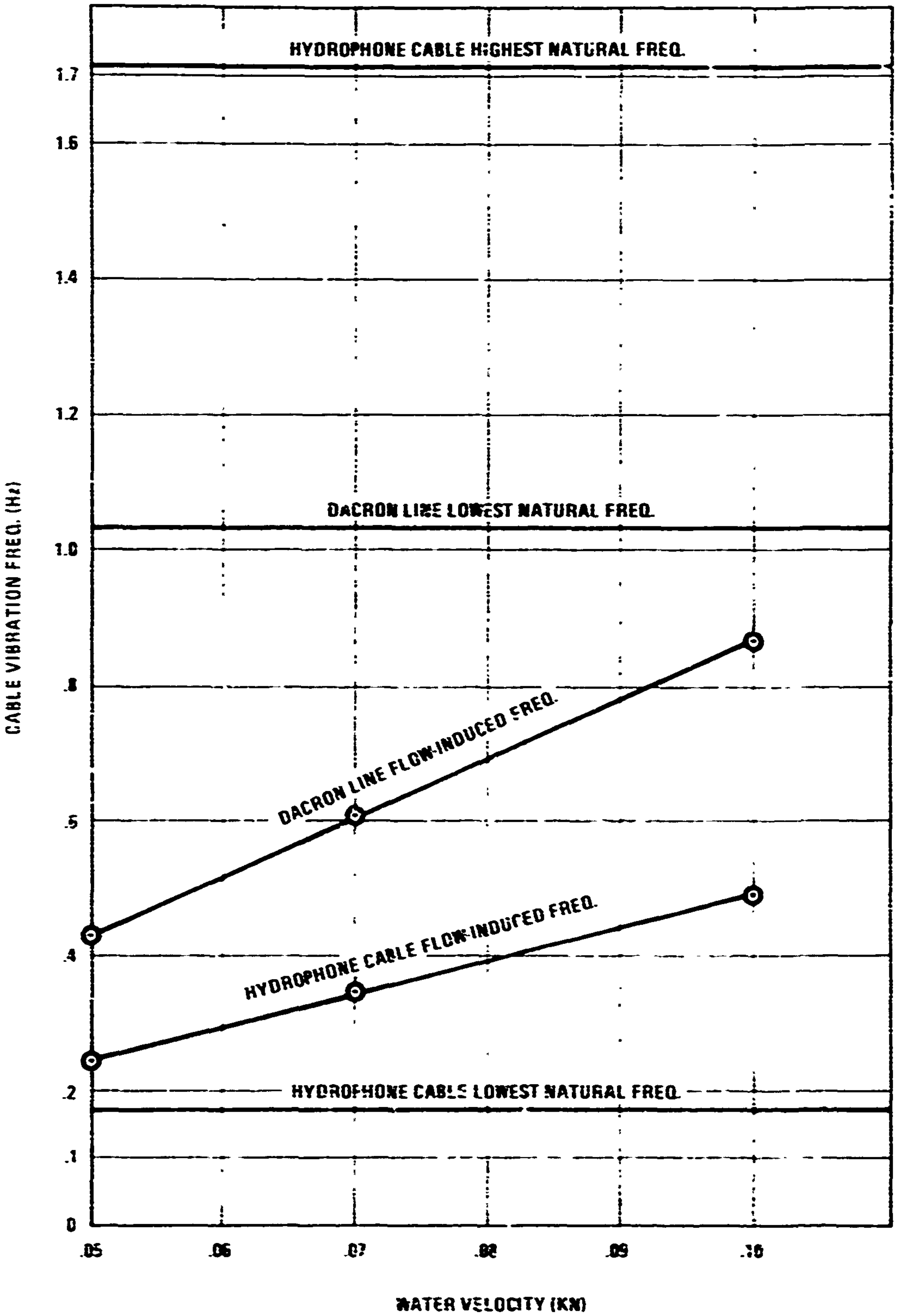


Figure 5-15. ATA Cable Vibration

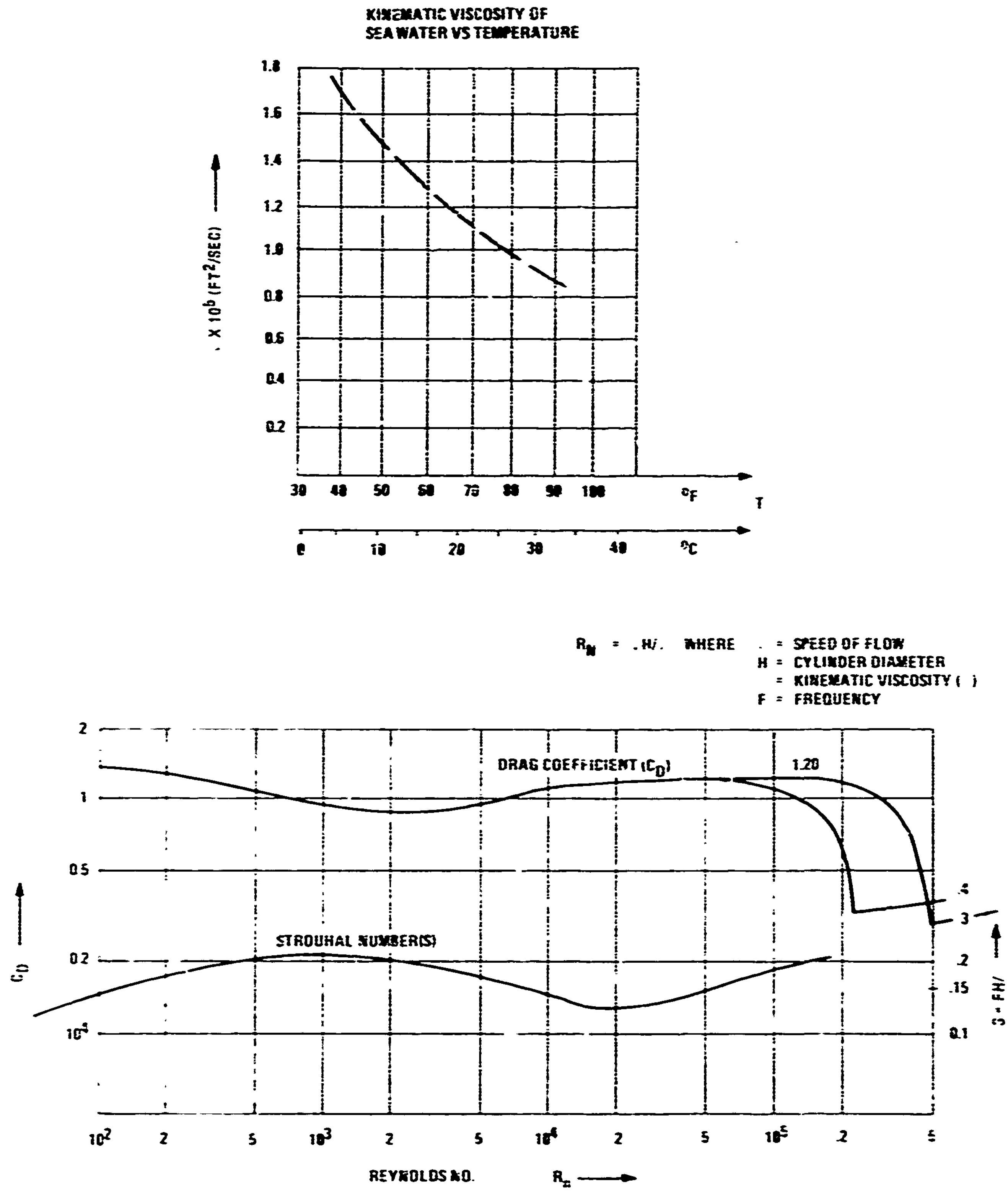


Figure 5-16. Drag Coefficient and Strouhal Number for Flow Past a Circular Cylinder (with L/D = ∞)

(U) The vortex shedding frequency, f_s (Hz) is a function of the water velocity, V, cable diameter, d (ft) and Strouhal number, S_t (dimensionless)

$$f_s = \frac{S_t V}{d}.$$

The frequency of the side acting oscillatory forces which are normal to the water flow is usually equal to the frequency of the alternating vortex shedding and is the fundamental or primary frequency of cable oscillation. Figure 5-17 illustrates this relationship for a range of diameters and velocities.

(U) Other oscillatory drag forces act at the rear of the cable, parallel to the water flow. These forces are caused by secondary vortices which are generated in the free shear layers in the near wake of the cable and are initiated by the transition from laminar to turbulent flow. Their mean frequency is represented by

$$f_t = \frac{0.025\ V^{1/2}}{(\nu\ d)^{1/2}}$$

and is illustrated in Figure 5-18 for a range of cable diameters and velocities. Flow studies have indicated that the excitation frequencies of secondary vortex generation are from two to four times the Strouhal frequencies. Studies have also shown that these forces are only about 1/10 of the forces of the Strouhal or primary oscillating forces and are, therefore, usually of less concern than the primary mode of vibration.

(U) Accordingly, we have considered that the Strouhal frequency will be the most critical flow-induced frequency.

(U) For our array the flow-induced frequencies for both the dacron line and the Hydrophone cable are shown in Figure 5-15 to be well below 1 Hz, and the harmonic-induced frequencies are assumed to be negligible.

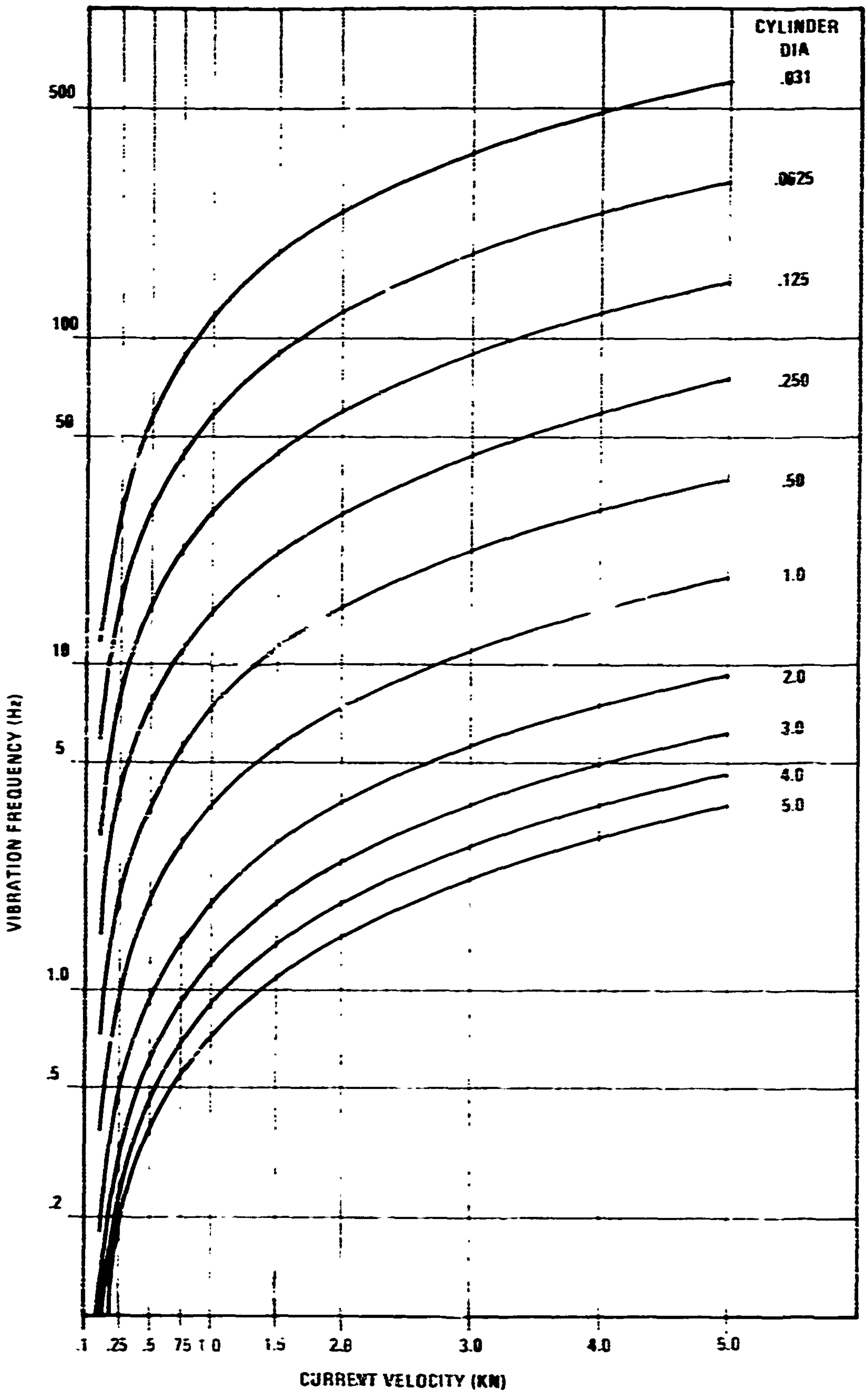


Figure 5-17. Flow Induced Vibration of Cylinders by Primary Vortex Generation (Strouhal No. = 0.18)

(U)

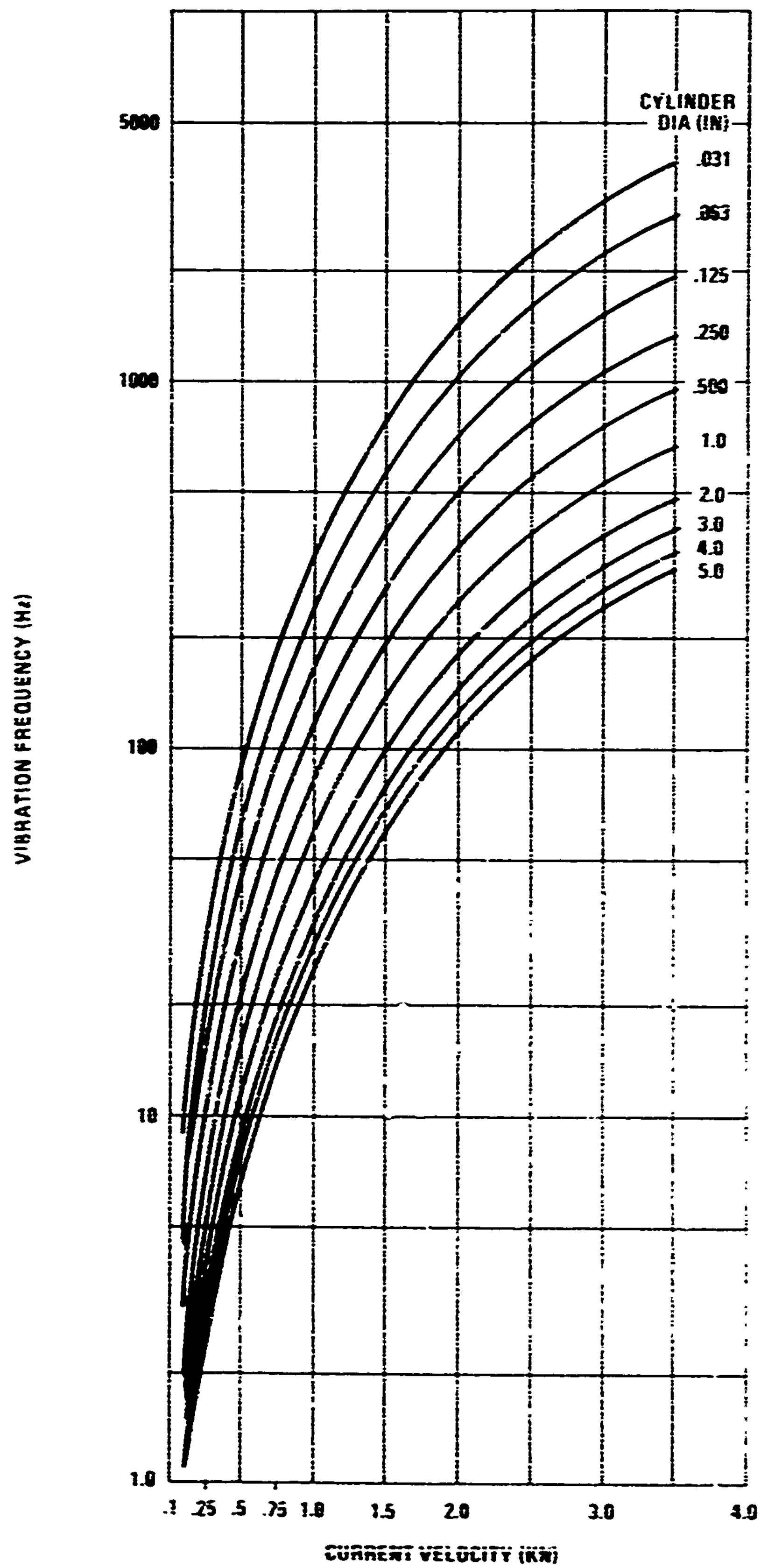


Figure 5-18. Flow Induced Vibration of Cylinder by Secondary Vortex Generation

(U) 5.8.4 Prediction of Cable Vibration

(U) Figure 5-15 also shows that the frequencies of the dacron line induced by .05 to .10 knot currents are lower than the lowest natural frequency we expect the line to have.

(U) The hydrophone cable, while it can be forced to vibrate, will apparently tend to do so at low frequencies which will be well outside the frequency band of interest.

(U) There is a possibility that the fundamental frequency induced in the hydrophone cable has overtones at higher frequencies. However, at these higher frequencies the amplitudes will be correspondingly smaller.

(U) Calculations were made of the amplitude ratio between the forcing frequency of the strumming phenomena and the natural frequency of the array cable. The relationship between amplitude ratio (y_o/y_i) and frequency ratio (f/f_n) is expressed by:

$$\frac{y_o}{y_i} = \frac{1}{\sqrt{\left[1 - \left(\frac{f}{f_n}\right)^2\right]^2 + \left(2\frac{C}{C_c}\frac{f}{f_n}\right)^2}}$$

where $\frac{C}{C_c}$ is

the damping ratio. Assuming very little damping — $\frac{C}{C_c} = 0.1$ — and a worst case water velocity of 0.10 knot for highest frequency induced vibration the first overtone (or second harmonic) at approximately 1 Hz would have an output amplitude of 1/3 the input amplitude at the induced fundamental frequency of approximately 0.5 Hz. Figure 5-19 illustrates the further reduction of amplitude at higher harmonics and with greater damping ($C/C_c = 0.8$). For example, at the fourth harmonic frequency of 2 Hz the amplitude ratio would be 0.06.

(U) One design feature which will help to prevent and damp cable vibration is the spreading out of 10 cylindrical transducers along the whole cable length. Hydrodynamic and effects of the flow around short cylinders tend to inhibit periodic vortex shedding. Another design area where improvements may be achieved is in lowering the cable tension to reduce further

(U)

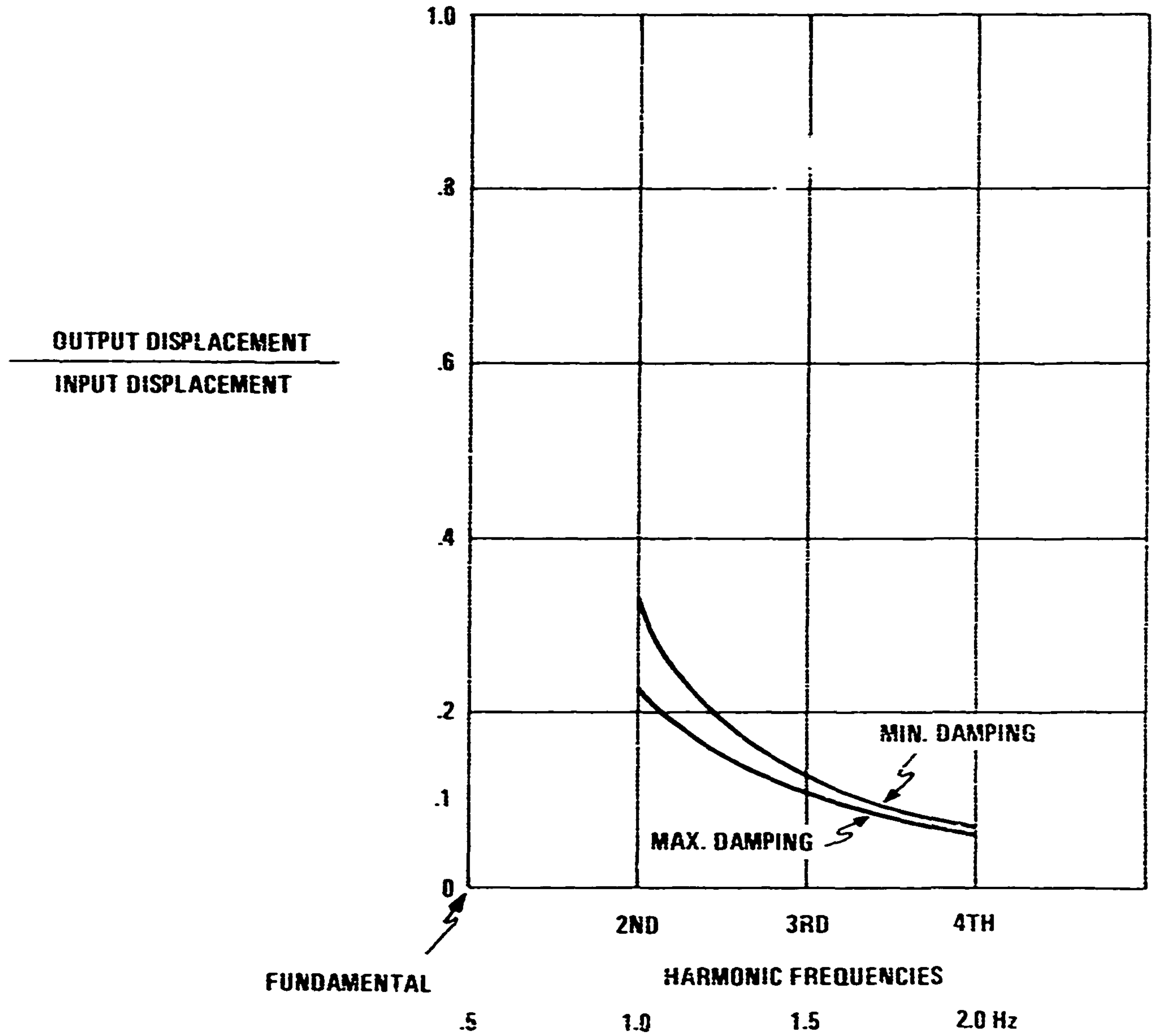


Figure 5-19. Amplitude Ratios of ATA Cable Vibrations at Harmonics of Flow Induced Frequency

(U) the lowest natural frequency. To achieve this, weights of the cable, transducers, and hardware would have to be reduced further allowing the buoyancy of the supporting buoy to be reduced also.

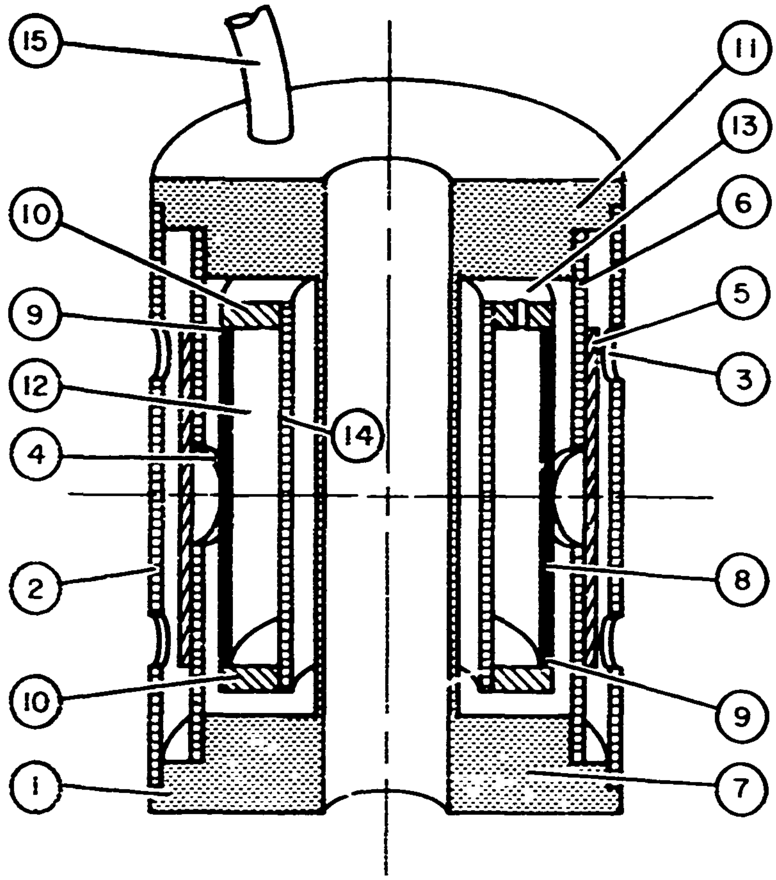
(U) 5.9 Hydrophones

(U) Because of the signals that can be introduced into the hydrophone by strumming of the cable caused by the flow of water, vertical acceleration cancelling hydrophones will be used on the vertical strings of the array. This type of hydrophone is used to cancel out any signals due to vibration or strumming of the cable. Vibration cancellation hydrophones having signal cancellation characteristics are quite well known and understood by many manufacturers, and are available from many sources. Essentially the hydrophone is divided into two horizontal sections and connected so that any vibration in the vertical plane will create voltages of opposite polarity in each half that will cancel each other out, whereas vibrations being received in the horizontal plane will allow the signal voltages to be added. An examination of a report by Earl D. Squier (Reference 5) indicates that many vertical acceleration cancelling hydrophones are available that would be applicable for use on the ATA. All exhibit very similar acoustical responses as well as acceleration cancelling properties. We, therefore, have a large choice of manufacturers to choose from.

(U) The hydrophone elements of the array will probably utilize pressure compensated piezoelectric cylinders operating in the hoop mode and balanced for acceleration cancelling. There will be a center hole through the hydrophone and attached preamplifier for the passage of the array cable.

(U) A cross-section sketch of a typical vertical acceleration cancelling hydrophone element is shown in Figure 5-20. The lead zirconate titanate cylinder is poled in the radial direction with the inside and outside surfaces as the silvered electrodes. The cylinder is thin-walled for maximum sensitivity and capacity. The element is oil-filled on the outside surface and on the inside surface through the capillary tube to provide the pressure equalization. This tube together with the inside volume is designed to resonate below the lowest operating frequency and thus provide a flat response in the operating range. The fluid and capillary size are chosen to provide viscous damping for this resonance.

(U)



1. HYDROPHONE SPOOL
2. OUTER PROTECTIVE COVERING
3. OUTER ACOUSTIC OPENING
4. INNER ACOUSTIC OPENING
5. PLASTIC ACOUSTIC WINDOW SLEEVE
6. ACOUSTIC WINDOW SUPPORT SLEEVE
7. HYDROPHONE CHAMBER, COMPLIANT OIL MEDIUM
8. PIEZOCERAMIC CYLINDER
9. PLASTIC SUPPORT RING
10. SUPPORT TUBE END RING
11. SUPPORT TUBE
12. COMPLIANT FLUID CHAMBER
13. PRESSURE EQUALIZING CAPILLARY
14. SUPPORT TUBE WEB
15. HYDROPHONE LEAD WIRE

Figure 5-20. Vertical Cancellation Hydrophone Manufactured by Westinghouse

(U) At the other extreme of the spectrum, the bandwidth is limited by the resonance of the cylinder, diffraction effects, and the loss of transmission through the acoustic apertures in the protective metal housing. In operation, a received sound wave passes through apertures and alternately compresses and relaxes the ceramic cylinder. The full free-field pressure produces this force since in the operating band, the diameter of the cylinder is much smaller than the wavelength of sound. Also, this pressure is not communicated to the inside of the ceramic cylinder because of the inertia and capillary viscosity of the oil in the connecting tube. Since the fluid interior to the ceramic cylinder has a finite stiffness, there is some reduction in the output sensitivity below that of an air-backed cylinder.

(U) The cancellation of accelerations along the axis is due to the mounting of the cylinder assembly at the plane midway along the axis. This cylinder assembly makes mechanical contact at both the ends of the ceramic cylinder. Thus, for motions along the axis, one half of the cylinder is compressed and the other half goes into tension yielding opposite voltage polarities and thus cancelling.

(U) Typical specifications for this type of element are listed in Table 5-1.

Table 5-1. Typical Element Specifications

(C)

Electrical
Sensitivity: -84 dB re 1V/μd,5 to 3000 Hz (without pre-amp)
Noise Level: below lower Wenz curve 5 Hz to 400 Hz
Source Capacity: 5000 pF
Acceleration Response: -60 dB re 1V/g
Mechanical
Size: 2.8" diameter x 8" long
Weight: 1.5 kg
Depth Capability: 20,000 ft
Mounting: can be mounted concentric with a cable to be winchable without having to disconnect from cable.

6.0 RELIABILITY

6.1 Failure Criteria

The failure criteria for the acoustic test array must be established in terms of the user of the data. The design requirement of a one year operating life with 90% confidence may then be applied to test the system design and to modify it, if necessary. It is assumed that all system functions and components are operating satisfactorily at the time of deployment and that graceful degradation of the system is permitted to some acceptable minimum required condition. This is intended to assure the user of sufficient data access at all times and that the system meets or exceeds the minimum required condition. While the user may still obtain considerable data in the absence of catastrophic failure, the system will be considered to be in a failed condition as soon as it fails to meet the minimum requirements specified in this section. The definition of full accessibility used below means that a hydrophone output at any commanded gain setting may be called for as one of the ten outputs to be transmitted to shore.

The failure criteria for the Basic, the Recommended, and the Expanded Systems are specified below. Four criteria, all of which must be satisfied simultaneously, are given for each system. The system will be considered to be in a failed condition if any one of the criteria is not met.

6.1.1 Basic System

Four vertical strings of five hydrophones:

- At least three hydrophone outputs from each of three vertical strings shall be fully accessible.
- At least three hydrophone outputs from each of three horizontal rows shall be fully accessible.

- One hydrophone pair with a horizontal spacing less than 1050 feet shall be fully accessible.
- Two hydrophone pairs with horizontal spacings greater than 3900 feet shall be fully accessible.

6.1.2 Recommended System

Four vertical strings of 10 hydrophones:

- At least five hydrophone outputs from each of three vertical strings shall be fully accessible.
- At least three hydrophone outputs from each of five horizontal rows shall be fully accessible.
- One hydrophone pair with a horizontal spacing less than 1050 feet shall be fully accessible.
- Two hydrophone pairs with horizontal spacings greater than 3900 feet shall be fully accessible.

6.1.3 Expanded System

Eight vertical strings of 10 hydrophones:

- At least five hydrophone outputs from each of five vertical strings shall be fully accessible.
- At least five hydrophone outputs from each of five horizontal rows shall be fully accessible.
- One hydrophone pair with a horizontal spacing less than 4200 feet shall be fully accessible.
- Two hydrophone pairs with horizontal spacings greater than 17500 feet shall be fully accessible.

These criteria have influenced the system configuration as well as the design of the array and the station electronics, which are discussed in other sections of this report. A matrix of available horizontal spacings for the Recommended System, when any one vertical string of hydrophones is totally inaccessible, is shown in Table 6-1. The same matrix applies to the Basic System and a more complex matrix allowing up to three totally inaccessible hydrophone strings may be readily derived for the Expanded System.

Table 6-1. Available Horizontal Spacings for Recommended System

Accessible Hydrophone Strings*	Horizontal Spacings (ft) ⊏ Available, ⊠ Unavailable					
	250 (A-B)	1000 (C-D)	4000 (B-C)	4250 (A-C)	5000 (B-D)	5250 (A-D)
B C D	⊠			⊠		⊠
A C D	⊠		⊠		⊠	
A B D		⊠	⊠	⊠		
A B C		⊠			⊠	⊠

*Exactly one totally inaccessible hydrophone string.

(Acoustic Test Array)

6.2 Reliability Model Approach

Initial work with the failure criteria presented in Section 6.1 makes clear the fact that to consider individual hydrophone path failures would result in a model which is unnecessarily complex. The approach taken, then, was to derive equations considering electronic failures down to each half-substation and calculate a system MTBF for the case where individual hydrophone path failures are neglected and for the case where any hydrophone path failure causes failure of the associated half-substation. It is clear that the actual MTBF will be in between the two values thus calculated; the optimistic case considers the reliability of the hydrophone paths to be unity, while the pessimistic case assumes any hydrophone failure to cause failure of the associated half-substation. Using this approach, the criteria given in Section 6.1 may be applied to the system by considering the number of half-substation failures which may occur while retaining the capability of receiving signals from the required combinations of hydrophones.

6.3 Reliability Mathematical Models

The minimum system consists of four strings, each containing five hydrophones divided so that two hydrophones operate through one half-substation and three through the other half-substation. If the failure criteria are that (1) signals from at least three hydrophones on at least three strings (vertical) and (2) signals from at least three hydrophones on at least three horizontal layers must be available for system success, the reliability equation is

$$R(t) = \epsilon^{-8\lambda t} + 8\epsilon^{-7\lambda t}(1 - \epsilon^{-\lambda t}) + 22\epsilon^{-6\lambda t}(1 - \epsilon^{-\lambda t})^2 +$$

$$28\epsilon^{-5\lambda t}(1 - \epsilon^{-\lambda t})^3 + 17\epsilon^{-4\lambda t}(1 - \epsilon^{-\lambda t})^4 + 4\epsilon^{-3\lambda t}(1 - \epsilon^{-\lambda t})^5$$

where

λ = the failure rate per half-substation path.

This equation is derived by assuming that failures are exponentially distributed with time. The first term, then, represents the probability that all eight half-substations will succeed. The second term represents the eight combinations when system success is achieved with seven half-substations succeeding and one failing, etc.

Expanding, collecting like terms and integrating from t = 0 to t = ∞ gives the MTBF as follows:

$$\text{MTBF} = \frac{4}{3\lambda} - \frac{3}{4\lambda} = \frac{7}{12\lambda}$$

The Recommended system consists of four strings each containing ten hydrophones equally divided between half-substation paths. Failure criteria are (1) signals from at least five hydrophones on at least three vertical strings and (2) signals from at least five hydrophones on at least three horizontal layers must be available for success. The reliability is given as:

$$\begin{aligned} R(t) = {} & \epsilon^{-8\lambda t} + 8\epsilon^{-7\lambda t}(1-\epsilon^{-\lambda t}) \\ & + 28\epsilon^{-6\lambda t}(1-\epsilon^{-\lambda t})^2 + 56\epsilon^{-5\lambda t}(1-\epsilon^{-\lambda t})^3 \\ & + 34\epsilon^{-4\lambda t}(1-\epsilon^{-\lambda t})^4 + 8\epsilon^{-3\lambda t}(1-\epsilon^{-\lambda t})^5 \end{aligned}$$

$$\text{MTBF} = \frac{8}{3\lambda} - \frac{6}{4\lambda} - \frac{16}{6\lambda} + \frac{24}{7\lambda} - \frac{9}{8\lambda} = \frac{45}{56\lambda}$$

The maximum system consists of eight strings of ten hydrophones each, where the hydrophones are equally divided between half-substation paths. The failure criteria are: 1) Signals from at least five hydrophones on at least five vertical strings containing at least one of any three adjacent strings and 2) signals from at least five hydrophones on at least five horizontal layers must be available for system success. The resulting reliability equation for this is:

$$\begin{aligned} R(t) = {} & \epsilon^{-16\lambda t} + 16\epsilon^{-15\lambda t}(1-\epsilon^{-\lambda t}) + 120\epsilon^{-14\lambda t}(1-\epsilon^{-\lambda t})^2 + \\ & 560\epsilon^{-13\lambda t}(1-\epsilon^{-\lambda t})^3 + 1820\epsilon^{-12\lambda t}(1-\epsilon^{-\lambda t})^4 + 4368\epsilon^{-11\lambda t}(1-\epsilon^{-\lambda t})^5 \\ & + 8002\epsilon^{-10\lambda t}(1-\epsilon^{-\lambda t})^6 + 11,380\epsilon^{-9\lambda t}(1-\epsilon^{-\lambda t})^7 + \\ & 7850\epsilon^{-8\lambda t}(1-\epsilon^{-\lambda t})^8 + 3600\epsilon^{-7\lambda t}(1-\epsilon^{-\lambda t})^9 + 952\epsilon^{-6\lambda t}(1-\epsilon^{-\lambda t})^{10} \\ & + 100\epsilon^{-5\lambda t}(1-\epsilon^{-\lambda t})^{11}. \end{aligned}$$

From this,

$$\text{MTBF} = \frac{100}{5\lambda} - \frac{208}{6\lambda} + \frac{60}{7\lambda} + \frac{170}{8\lambda} - \frac{180}{9\lambda} - \frac{3058}{10\lambda} + \frac{15,632}{11\lambda} - \frac{32,950}{12\lambda}$$

$$+ \frac{37,400}{13\lambda} - \frac{24,110}{14\lambda} + \frac{8364}{15\lambda} - \frac{1219}{16\lambda}$$

6.4 Relative Reliability of the Three Systems

As the system goal is a one-year MTBF with 90% chance of success, the actual predicted MTBF must be about 83,000 hours, or about 10 years.

$$\text{Reliability} = \text{Probability of Success} = \epsilon^{-\lambda_{eq} t} = .90$$

where

λ_{eq} = Equivalent system failure rate

t = Time = 8760 hours (1 year)

$$\lambda_{eq} = \frac{(-\ln .90)}{8760 \text{ hrs.}} = \frac{.10536}{8760} = 12 \text{ failures}/10^6 \text{ hours}$$

$$\text{MTBF} = \frac{1}{\lambda_{eq}} = \frac{10^6}{12} = 83,333 \text{ hours.}$$

Equating the three equations for MTBF derived in Section 6.3 to 83.333 hours and solving for λ, it is seen that the required failure rates for a half-substation are as follows:

Basic System	$\lambda = 6\ f/10^6$ hours
Recommended System	$\lambda = 9.7\ f/10^6$ hours
Expanded System	$\lambda = 9.7\ f/10^6$ hours

It is clear that since the Recommended and Expanded systems have more built-in redundancy, the MTBF of 83,333 hours can be met with a half-substation failure rate of $9.7\ f/10^6$ hours, whereas the half-substation failure rate must be only $6\ f/10^6$ hours for the minimum system to meet the same MTBF.

6.5 Predicted Failure Rate of Chosen Electronic Components

Using the information regarding the physical make up of the system, failure rates for the system functions were estimated. Basic assumptions made in order to predict the component failure rates per RADC-TR-67-108, Vol. 2, are:

- The environment experienced in a deployed unit is equivalent to "laboratory;" i.e., minimal shock and vibration, constant temperature, pressure and humidity.
- Temperature is 4°C.
- Component quality grade is "upper" or, in the case of IC's, "optimum," or equivalent to MIL-STD-883, Class A.

The failure rate used for the RCA CD4000 COS/MOS logic elements was based on private communication from RCA combining the results of two long-life tests. The resultant failure rate was .02 f/10^6 hours (60% confidence) at 25°C, based on 2 million device hours at 125°C with zero inoperable failures.

Based on the failure rates thus calculated, Table 6-2 gives resulting failure rates and expected MTBF's for the three system configurations. Because of the fact that the failure rate for the hydrophone paths is small, (25%) of the half-substation failure rate, the actual MTBF will be closer to the figure given, excluding the effect of the hydrophone paths.

Table 6-2. Calculated System Failure Rates

	Excluding Hydrophone Paths		
	Failure Rate/ 10^6 hours	MTBF (hours)	Confidence of 1 Year Life
Basic System	2.9096	171,000	95.0%
Recommended System	2.9096	277,000	96.8%
Expanded System	2.9096	277,000	96.8%
	Including Hydrophone Paths		
	Failure Rate/ 10^6 hours	MTBF (hours)	Confidence of 1 Year Life
Basic System	4.3812/5.1170	114,000/97,500	92.6%/91.4%
Recommended System	6.5886	123,000	93.1%
Expanded System	6.5886	123.000	93.1%

7.0 PROGRAM PLAN

The Acoustic Test Array can be designed, developed, fabricated and ready for implant within 9 months after contract award providing the plan and schedule herein are vigorously and aggressively pursued by all organizations and agencies involved.

Although the program milestones are referenced as months after contract award, it is significant to note that sea-state conditions in the implant area deteriorate in the fall of the year. Prudent planning dictates an implant no later than September but an earlier planning date would provide assurance against any unforeseen schedule slippage.

It should also be noted that, since we are unaware of any specific plan for the display and processing of data in the shore station, this program element is not included in the Raytheon/Vitro program plan.

Four important control milestones have been incorporated into this plan:

1) Systems Requirements Review (SRR) and Approval
2) Preliminary Design Review (PDR) and Approval
3) Final Design Review (FDR) and Approval
4) Acceptance.

The Systems Requirements Review and Approval will take place coincident with the start date, assuming that the contract is issued for an exact system as described in the preceding chapters, and any changes are defined prior to the start date. At this milestone, a preliminary systems specification in contractor format will be reviewed and approved. It will contain sufficient detail so that component specification for vendor procurement can be written and the planning for component and systems development testing can commence.

Preliminary design approval will be required by the end of the 5th week. The preliminary design will consist of engineering sketches, functional electrical schematics, and mechanical layouts of the Acoustic Test Array and shore station central unit.

Final design approval will be required at the end of the 26th week (36th week of the two-phase program). The final design will consist of a systems specification, MIL-D-1000, Class C, Form 3 drawing for the entire system, evaluation of development and environmental tests, and the implant test plan.

Systems acceptance will be required for the end of the 36th week (60th week of the two-phase program) to maintain schedule. This will consist of Government review/inspection in accordance with an approved acceptance procedure in contractor format.

In addition to the control milestones, the program plan has been divided into several tasks. Specific milestones and criteria have been established for each task and the plan has been developed so that these criteria must be successfully met prior to implant of the system. The tasks and their goals will be briefly described in the next paragraphs.

Four distinct tasks make up the program schedule, culminating in the system implant, planned for execution 9 months (16 months for the two-phase program) after start of the contract. The program tasks are:

1) the design and development task
2) developmental prototype fabrication and test
3) prototype equipment evaluation, including at-sea training and prototype equipment deployment
4) system hardware and system implant.

The design and development task will include the electrical and mechanical design, breadboard layout, and an early at-sea implant of a test unit.

The second task, development prototype equipment fabrication, test and evaluation program, will develop the substation and electronics and mechanical packaging, interstation cable, vertical array cable (with representative hydrophones), and high pressure penetrations. In this phase, the equipment is to be thoroughly evaluated with laboratory tests. both for electrical reliability and failure modes and for mechanical integrity at high pressures. Following a review based on the laboratory test results and the equipment design, the at-sea

development prototype tests will begin. The at-sea developmental tests will verify that the system deployment techniques and prototype equipment design are satisfactory by both shallow water and deep water testing and retrieval.

After satisfactory systems evaluation, the prototype equipment deployment and system implant will be completed. In the third task, the prototype equipment will be updated as far as practicable to reflect the final system. The system will be taken to sea, implanted and recovered to train the implant crew and demonstrate system readiness. The final system will be completed, acceptance tested and shipped. Final system implant will follow completion of system dockside testing.

7.1 Design and Development Task

The design and development task will encompass the design of the acoustic test array, special ship handling equipment, and the design and fabrication of a test unit. The electrical design will begin with the concept outlined in this study and as modified by ONR selection of trade-offs. Based on the system design specification, the subsystem electrical design will be developed, followed by breadboard and electrical tests to demonstrate that the design meets the requirements. After the development of the design to this extent, documentation for the pilot system will begin. One part of the design and development task includes the fabrication of a test unit to be deployed early in the program to verify SDC transmission characteristics and evaluate proposed electronic housing seals and bulkhead penetration design.

The test unit has been scheduled for implant 9 weeks after start of contract. This schedule would be unreasonable except that an in-house research and development program is underway which will support the design and fabrication of a length of interstation cable and vertical cable and the design and breadboard of simplified electronics. Effort remaining after contract start to complete the test unit would include the fabrication of the electronics cavities and attachment to the SDC cable. This can be accomplished within 9 weeks. It should be noted that the primary function of this test implant will be to evaluate several seal designs and obtain corrosion data at the site during a 3- to 4-month period. Retrieval of the test unit at the end of 3 1/2 months will be required in order to obtain inputs for the design of system equipment.

7.2 Developmental Prototype Fabrication and Test

The purpose of the developmental prototype task will be to demonstrate that the equipment design and fabrication techniques are suitable for fabrication of the system equipment. In order to demonstrate this design suitability, the prototype equipment will be thoroughly tested and evaluated. The tests include repeated laboratory tests of vertical array cable payout, hydrostatic tests of all cable assemblies and pressure vessels, and electrical tests and temperature cycling of all electronics equipment. After satisfactory completion of these tests, the equipment will be tested extensively at sea in order to develop proper shipboard handling techniques as well as demonstrate substation deployment and vertical array erection in shallow and deep water. Only after satisfactory completion of this task will a decision be made to fabricate system hardware and perform the prototype equipment deployment tests.

7.3 Pilot Equipment Evaluation and Crew Training

In this task, the prototype equipment used for the previous substations will be refurbished, vertical array cable assemblies will be replaced, and system electronics will replace prototype equipment. Dummy substations will also be available in order that a small acoustic test array can be simulated in all respects. This pilot array will be installed on the cable laying vessel to be used for implant of the system equipment. Beginning with dockside prototype equipment tests, the tests will become increasingly complex until the pilot system has been properly deployed and recovered. In this way, the ship's crew will learn all aspects of system implant and will learn to work together as a team. Only upon satisfactory completion of these tests will the decision be made to perform the final system implant.

7.4 System Hardware and Implant

The fabrication and checkout of system hardware is scheduled to begin 26 weeks after the start of the program, based on the successful conclusion of the developmental prototype equipment tests. Although long-lead system hardware requirements for interstation cable, vertical array cable, and hydrophones must be committed earlier, the major fabrication and labor costs for substation, bulkhead penetrations and commitments for cable laying ships, cable

engines, etc., will only be made in the 26th week of the program. Fabrication of the system will take place during the pilot equipment evaluation, except in the two-phase program where it will take place serially after an evaluation of the pilot system. Shipment of the system will take place after equipment burn-in and completion of system tests. The system equipment will again be system tested on the ship at dockside and implanted after approval by the program manager.

7.5 Program Schedule

The recommended program schedule is shown in Figure 7-1. It is a 9-month effort to dockside readiness with milestones as illustrated. It is apparent that long-lead hardware must be identified at the preliminary design review, which emphasizes the importance of the control milestones.

A two-phase program was suggested during reviews with ONR while this report was being generated and is illustrated in Figure 7-2. It is a 15 1/2-month program to dockside readiness. The 6 1/2-month difference between the two programs is required to allow for serial deployment and evaluation of a pilot system prior to final design approval. Although this schedule relieves some of the risk inherent in the shorter, single-phase program, it should be noted that long-lead hardware must still be ordered early to fabricate the pilot system.

Of significance to both schedules is the recommendation that the deployment not take place later than September. This requires a start date of not later than 1 December for the single-phase program. A start date earlier than 1 December is recommended for the single-phase program to provide some assurance against any schedule slippage.

A detailed program plan for the single-phase Recommended System, reflecting the milestone program, is shown in Figure 7-3.

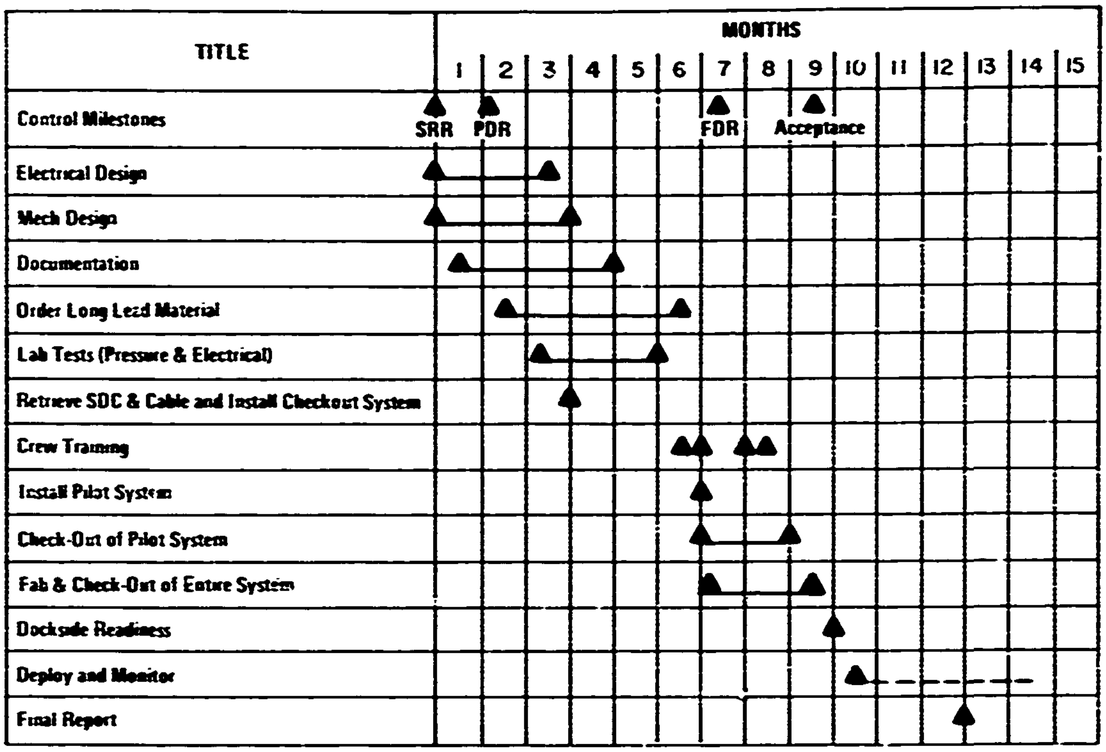


Figure 7-1. Acoustic Test Array, Single-Phase Program

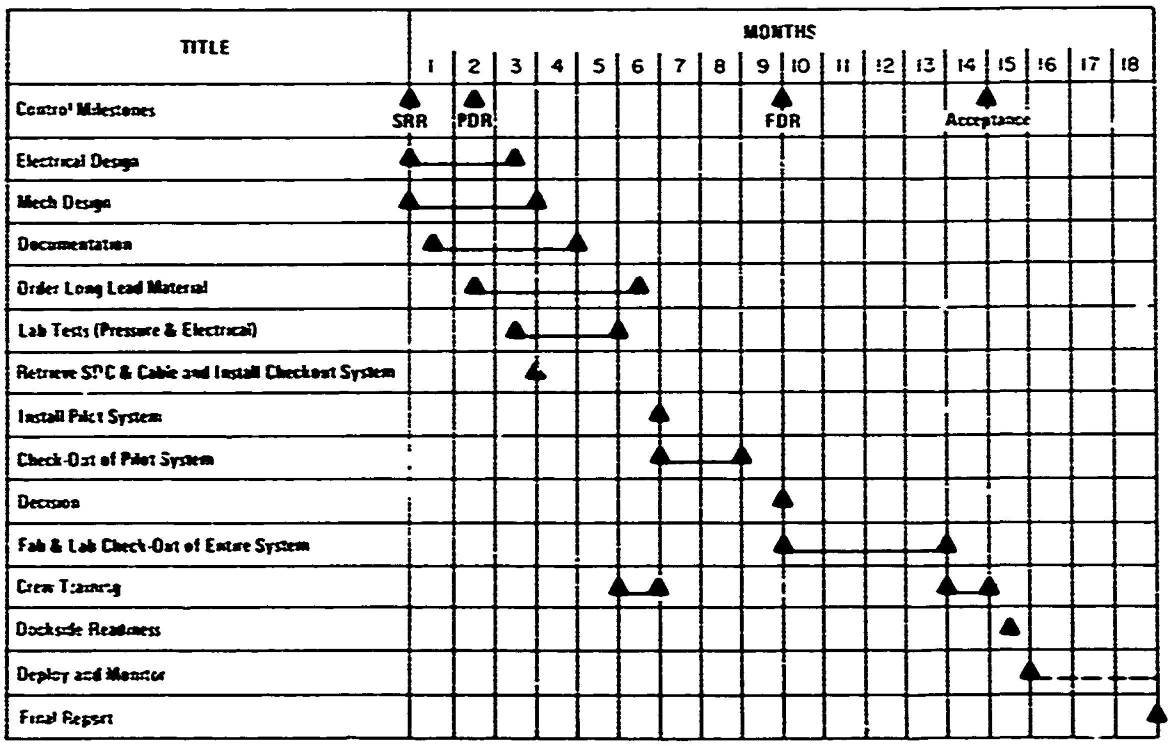


Figure 7-2. Acoustic Test Array, Two-Phase Program–Series Approach

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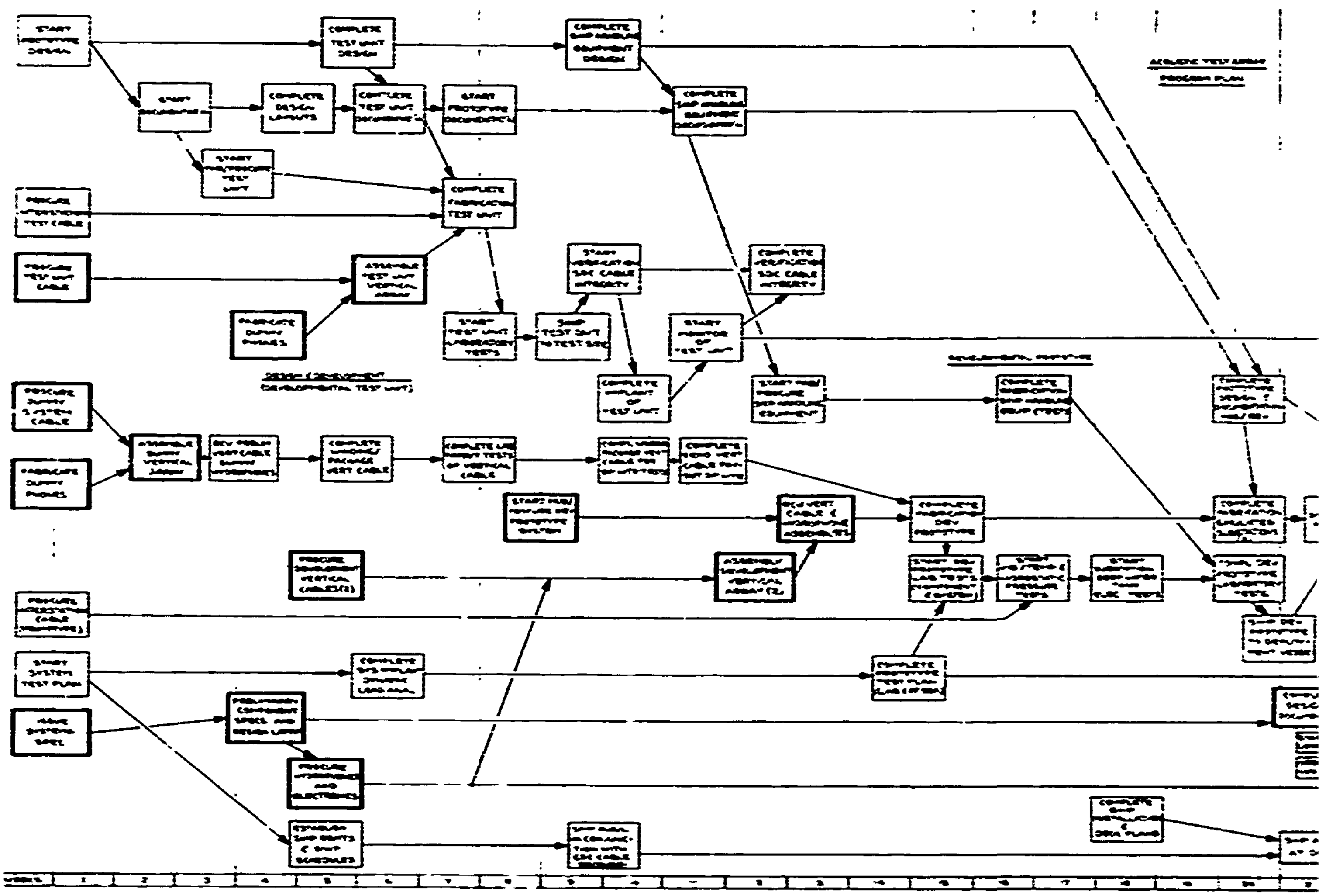

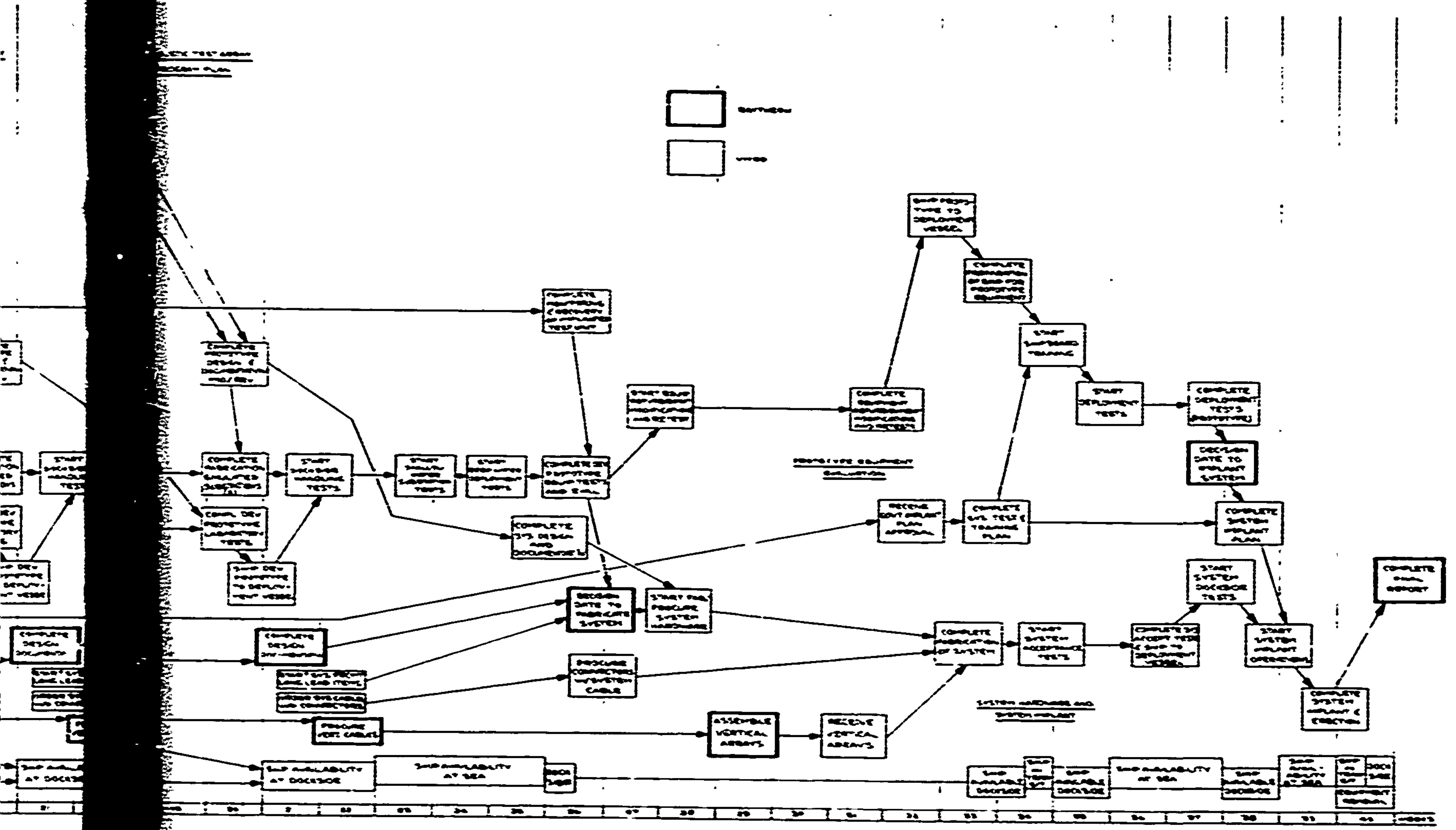

Figure 7-3. Detailed Program Plan for Single-Phase Recommended System

8.0 FACILITIES

8.1 Submarine Signal Division

The ASW Center at Submarine Signal Division is the largest industrial facility devoted exclusively to research, design, development, and manufacture of sonar and ASW systems and components.

Table 8-1. Submarine Signal Division Facilities

Location	Function	Operating Area
Building 1 Portsmouth, R.I.	Engineering and Division Headquarters, ASW and Environmental Systems, including all Laboratory, Drafting, and Program Management. Built in 1960.	137,000 sq. ft.
Building 2 Portsmouth, R.I.	Manufacturing, including Final Test. Built in 1966.	100,000 sq. ft.
Building 3 Portsmouth, R.I.	Ocean Systems Center, Purchasing, Raytheon Service Company, and Business Computing facilities. Built in 1968.	33,000 sq. ft.
Building 4 Portsmouth, R.I.	Central Warehouse, Receiving and Incoming Inspection. Also S & R Depot. Built in 1968.	40,000 sq. ft.
Building 5 Newport, R.I.	Integrated Logistics Support, Publications Department, and Environmental Research Lab.	30,000 sq. ft.

The Portsmouth facility is located near Naval establishments such as the Naval Underwater Systems Centers at New London and Newport, as well as U.S. Navy installations in Narragansett Bay and the Submarine Base at New London.

Raytheon's Submarine Signal Division has 0.34 million square feet of floor space and employs 1800 people. Over 500 of SSD's employees are scientists and engineers who are devoted to the unique problems of underwater acoustics that must be resolved to meet the ever-increasing enemy threat.

The Division's facilities have been tailored to provide the necessary equipment for the design, development, and production of ASW systems and components such as transducers, amplifiers, hydrophones, and their related hardware.

8.1.1 Scientific Computer Facility

This facility is capable of supporting data reduction, data analysis, display-simulation and other scientific programs required to support development programs at Submarine Signal Division. The computer facility, shown diagramatically in Figure 8-1, is set up as an integral part of the Data Reduction/Simulation Laboratory. The facility includes:

- Raytheon 520 Computer—The Raytheon 520 Computer (Figure 8-2) is a 16K digital computer located in the SSD's Data Reduction/Simulation Laboratory. Machine hardware includes 16K memory/24-bit word, card reader, line printer, paper tape reader and punch, Selectric typewriter, and three seven-track magnetic tape units. Interface is available for remote data source inputs and data outputs for remote display devices. This is accomplished through the Multi-Device Controller (MDC). An A/D converter and multiplexer convert information from sources such as an EAI TR48 analog computer or from an FR-1800 Ampex analog recorder. Several D/A converters are used to present analog outputs to devices such as plotters, oscilloscopes, or magnetic tape recorders. Provision has also been added to accommodate digital signals (both input and output) and multiple external interrupts. Other peripheral devices include an off-line tape preparation unit, CRT display, and an off-line Houston incremental plotter. Languages include: FORTRAN IV, Version 13; FORTRAN IV, Real Time; FLEXTRAN, Assembly Level; MACHINE LEVEL: METAPHRASE.
- IDIIOM Display—The Information Displays Incorporated Input/Output Machine (IDDIOM) (Figure 8-3) is a fully buffered graphic CRT console for people-language, man-machine dialogue. This system can be used for computer-assisted instruction, simulation, command and control, information retrieval, and human factor studies. Included in the IDIIOM configuration are:
  - 21-inch rectangular CRT
  - Light pen
  - Varian 620/i Computer with 12K memory
  - 32 function keys
  - ASE Model 35 teletype
  - High-speed paper-tape reader.

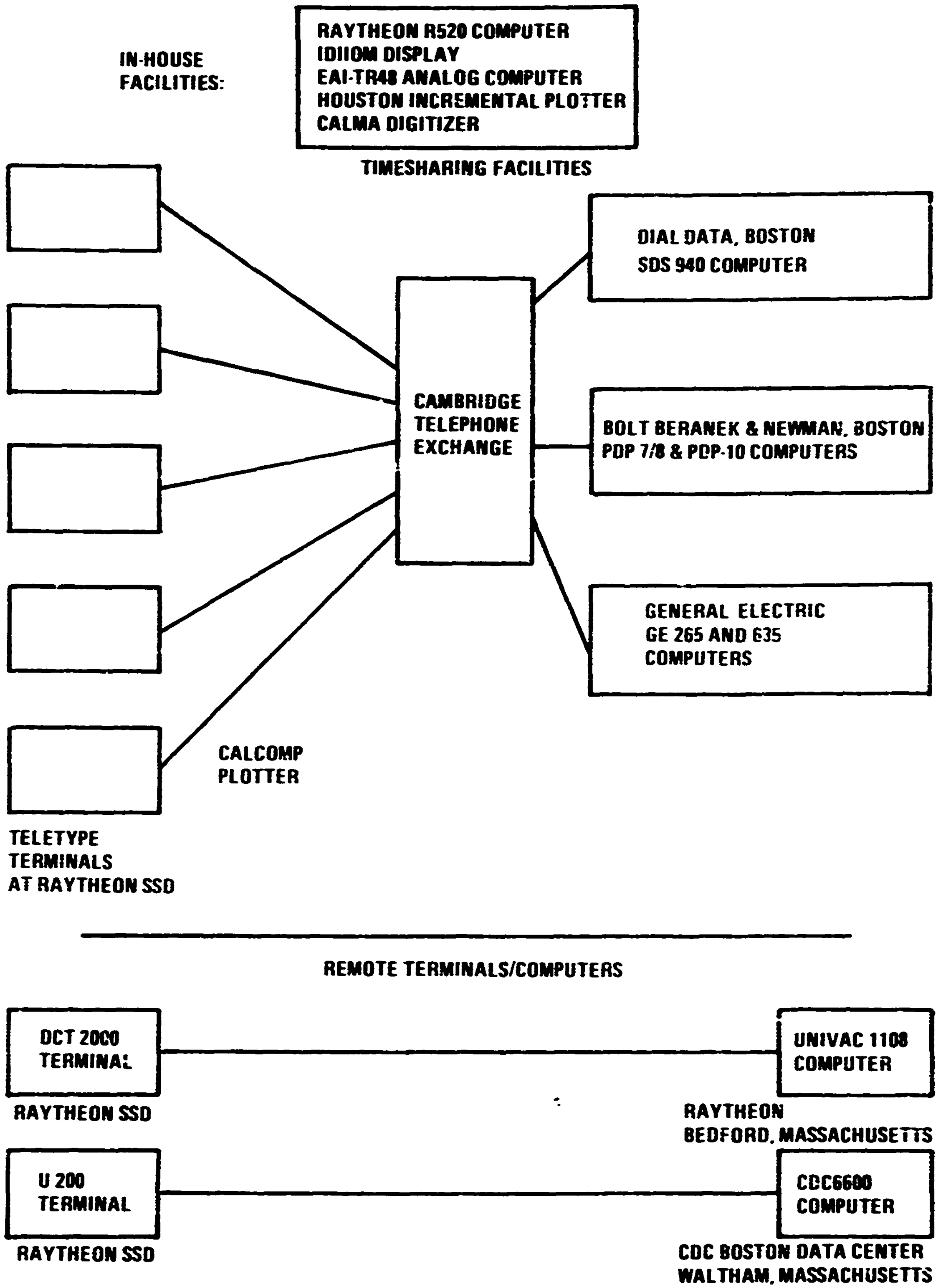

Figure 8-1. In-House Scientific Computer Facilities

Figure 8-2. Raytheon 520 Computer, Data Reduction/Simulation Laboratory

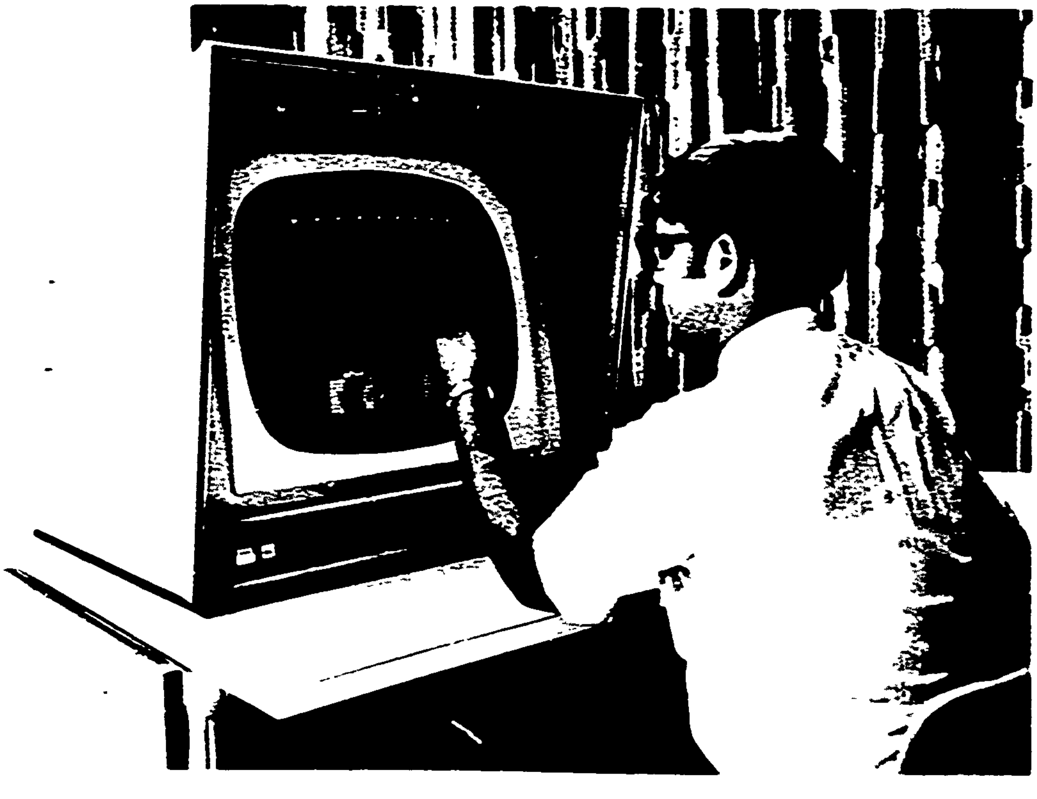

Figure 8-3. IDIIOM Display Data Reduction/Simulation Laboratory

Special modules are included for character writing, line and circle drawing. Four character sizes, four intensity levels, graphic element flashing, character rotation, and programmable line structure are hardware features of the IDIIOM. The IDIIOM is located within the Data Reduction/Simulation Laboratory.

- Remote Communication Terminals—In addition to the in-house 520 computer, Submarine Signal Division has access to five computer facilities via teletype and terminal hook-up. These five give the user a wide choice of computer size, programming languages, and use of different peripheral equipment. Two terminals are connected to large computers: a UNIVAC 1108 computer located at the Raytheon Corporate facility in Bedford, Massachusetts; and a CDC 6600 in Waltham, Massachusetts. In addition, three teletype units are located in Building 1, any of which may communicate with the small-to-medium size computer facilities indicated as Time Sharing Facilities (Figure 7-1). A Calcomp plotter is on site which may receive output from any of the three data services.

8.1.2 Narrowband Processing and Display Systems

Today's narrowband processing and display systems require a total system approach which reflects a comprehensive analysis and investigation of key parameters. Under company-supported development programs, Raytheon has designed and facricated a complete narrow-band processing and display system (Figure 8-4) to provide a test bed for signal processing studies and analyses. This system utilizes the R704 computer and array transform processor (ATP) for input processing, spectrum analysis, post-processing, and display format control. The design approach, control techniques, and post-processing are directly applicable to the Fast Time Analysis System. The Raytheon in-house system possesses the following features:

- Multi-channel operation
- Digital quadrature demodulation and filtering
- Digital FFT
- Constant bandwidth analysis by octave
- Vernier
- Automatic short/long term line integration
- Spectral normalization

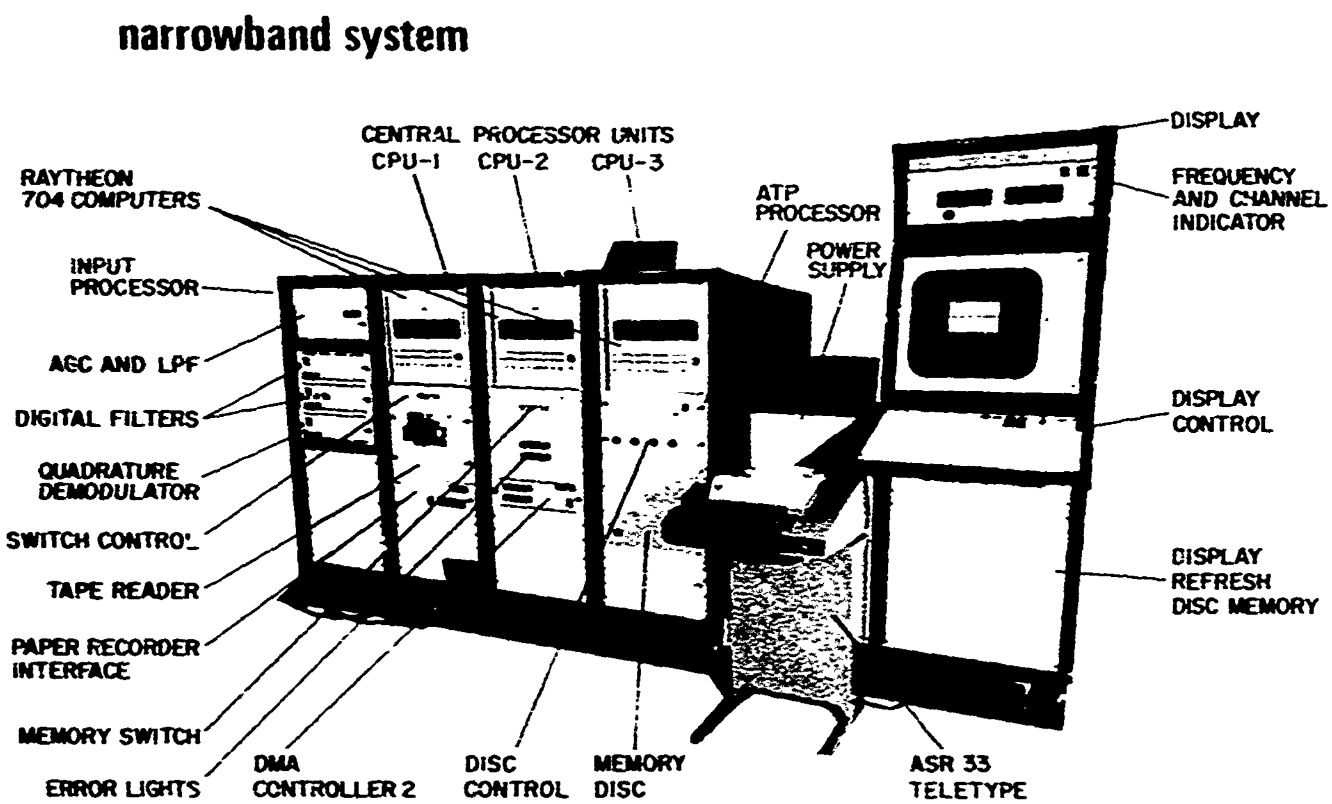

Figure 8-4. Raytheon's Narrowband Processing and Display System

- Threshold detection
- Frequency window alerting
- Self-noise removal
- Display formatting
  - Lofargrams
  - A-Scans
  - Threshold-detected data.

8.1.3 Acoustic Data Analysis Facility

The analysis of acoustic data is performed with a variety of processors. The analyses of the reduced data employ several automated computer analysis programs which sort the data over several parameters, allow for correction to the input data, check the distribution of data, average the data for various specified conditions, compute the standard deviations of the data, and produce final summary tables of both the input and processed data. Programs which produce hard-copy plots in report format have also been developed.

8.1.4 Transducer Facilities

A complete transducer laboratory (Figure 8-5) with special equipment for transducer experiments, as well as a fully-tooled machine shop and 20K psi test tank, support the developmental phases of transducer design. Also included is an indoor anechoic test tank which is equipped with various test and recording equipment and array handling devices. An open-water test facility and hydroacoustic laboratory is maintained and available for testing and evaluating transducers and sonar systems under simulated operational conditions.

8.1.5 Engineering Development Department

The Engineering Development Department is the hardware arm of the design function. The department is composed of four primary groups: Development Center, Machine and Sheetmetal Shop, Assembly Shop, and the Printed Wiring Laboratory. Department personnel, in an atmosphere of "quick reaction," fabricate prototype equipment and test models of ASW systems and components.

Figure 8-5. Transducer Laboratory

Independent laboratories are set up for transformer fabrication, chemical analysis, mechanical engineering, and special environmental tests using displays and lasers.

Department equipment includes numerically-controlled units for grinding, drilling, general lathe and milling work, and a semi-automatic wire-wrap system was installed this year. The assembly shop includes IC reflow equipment, hoists and elevating platforms. One area includes an overhead, five-ton bridge crane.

8.1.6 Manufacturing Facility

This facility was specifically designed for producing complex sonar systems and components. Two of the current production programs include the AN/BQS-11/12/13 and AN/BQR-19 sonar systems and associated transducers. The production area of this building is comprised of the following primary assembly areas: cable and harness, micro-miniature, chassis, and cabinet.

Test equipment facilities include 13,000 square of floor space, and nine test bays designed to simulate various conditions of the sonar system environment. An addition to this facility offers an open-water test barge, equipped with complete facilities for a range of transducer and hydrophone production tests.

8.1.7 Raytheon's Sea-Going Laboratory

In addition to the standard engineering facilities employed in the design, development, and production of ASW electronics, Raytheon is equipped with many facilities unique to sonar systems and equipment. One such facility is the recently commissioned 83-foot Motor Vessel SUB SIG to be used as an at-sea laboratory. This ship (Figure 8-6) is outfitted with a variety of test equipment to perform complementary acoustic analysis and will contain some of the near-future sonar systems development equipments. Some of her features and facilities are:

- 2700-Mile Cruising Range
- 12-Knot Cruising Speed
- 480 Square Feet of Lab Space
- Sonar Array Handling Gear
- Radar
- Radio
- Depth Sounders
- LORAN

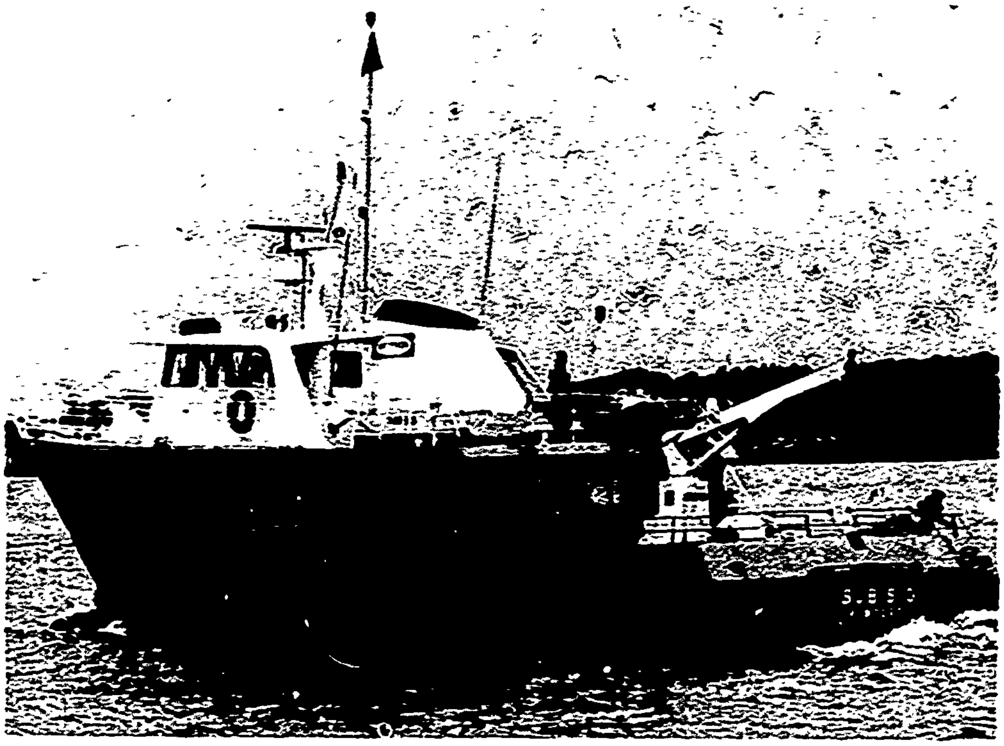

Figure 8-6. MV SUB SIG

8.2 Vitro Laboratories Facilities

Vitro Laboraotries Division is located in Montgomery County, Silver Spring, Maryland. The Laboratory houses computer, publications, and drafting facilities: drawing and document storage: development laboratories; technical library; microfilm facility: a central reproduction facility for the duplication of engineering documentation: machine shops: and other administrative and support offices. Approximately 500,000 square feet of working area is used.

Vitro Laboratory holds a Top Secret facility clearance which was issued 10 September 1971 by the Defense Contract Administration Service Region, Philadelphia, Pennsylvania.

8.2.1 Information Services Department

The Information Services Department (IS) provides publications and documents to support the Division in the performance of existing contracts, in keeping abreast of the state-of-the-art in rapidly changing technologies, and in expanding into new fields.

The Department has a carefully selected collection of approximately 12,000 books, 50,000 technical reports and manuals, and 350 periodical subscriptions in all fields of interest to the Division. Included in this collection are publications in all branches of physics, computer science, missilery, oceanography, urban affairs, transportation, ecology, system engineering, and management. In addition, there are thousands of engineering drawings, standards, specifications, military instructions and directives, manufacturers' catalogs, and miscellaneous documents, providing technical background for the Division's work. Aperture cards, microfiche, and other microforms are used along with the traditional hard copy. Over 200,000 items are added each year.

Various record and retrieval systems have been devised to accommodate different types of material and the needs of the users. Computer printout indexes, catalog cards for browsing, frequent regular announcement lists, and selective dissemination of documents are available. Reference services, including data and retrospective literature search, are provided. The Department is authorized to use the services of the Defense Documentation Center (DDC) and the National Aeronautics and Space Administration (NASA). The resources of many government, public, university, and association libraries are also available through interlibrary loan to supplement the Department's collections.

This Department has a staff of about 50 experienced personnel, including several with advanced degrees in librarianship and information science.

8.2.2 Computer Facility

The Laboratory's computer facility (in operation since 1962) is one of the largest commercial installations in the metropolitan Washington, D.C. area. It consists of a digital computer complex including two IBM System 360s (Models 65 and 30), and an IBM 7090.

Two CalComp Model 763/780 digital incremental drum-type plotters are available for output from the computers. These plotters operate off-line from 9-track 800-BPI magnetic tapes at a maximum speed of 900 steps/second, a maximum resolution of 0.0025-inch steps plus the Zip Mode equivalent to 1687 steps/second. Programs for conversion from 7-track to 9-track tapes for driving the CalComp plotters are available.

All equipments utilize the latest software which is maintained in-house on a continuing basis by our own staff of systems programmers. IBSYS Version 13 is used to monitor 7090 operations, and Basic Programming Support (BPS) is employed for the 360/30. The 360/65 operates under the MFT option of the full Operating System (OS) in a HASP environment which allows for the capabilities of multiprogramming, remote access terminals, and the use of the larger compilers. Programming is currently done in FORTRAN IV. COBOL, Assembler Language Coding (ALC), Report Program Generator (RPG), and Programming Language 1 (PL/1). Vitro also operates the Administrative Terminal System (ATS) in a multiprogramming environment for document preparation, remote terminals.

8.2.3 Vitro Wire Winding Dispenser Facility

Vitro's wire winding facility has over 21 years of experience in the production of wire and cable dispensers. Over 10,000 dispensers have been produced during this period, consuming over 50,000 miles of wire and cable. This experience spans the fabrication of experimental units and high volume production of standard wire dispensers. Internal and external payout dispensers have been wound using a variety of wires or cables and adhesives. Electrical single conductor insulated cables of up to 5/16-inch diameter have also been wound into dispensers in many different configurations. The winding facility possesses the ability to respond on short notice to special orders as well as maintaining production runs on standard dispensers.

Although the facility's main product is production and experimental torpedo wire dispensers in a variety of sizes and configurations, special dispensers have been fabricated for a wide spectrum of associated uses. Among these are four-conductor electrical cable of 0.0018-inch diameter, wound on an external payout mandrel, and designed for payout in air at speeds to 900 feet per second through a rocket nozzle exhaust. External payout dispensers have also been wound with 0.0035-inch diameter stainless steel wire to payout at speeds to above mach 2. Steel cables have been wound into internal payout dispensers with and without back-twist to payout in water or air at speeds to 250 feet per second. Electrical communication links using 0.038-inch diameter wire with spaced electrical repeaters have been wound into dispensers and payed out in water at speeds to 100 feet per second.

Most of the wire winding equipment employed has been designed and fabricated by Vitro or modified from special purpose commercial equipment. A Vitro-developed back-twister can apply any desired amount of back-twist per turn of the wound dispenser. All winding is performed under controlled tension conditions using feed mechnisms developed by Vitro. Adhesives can be applied automatically under controlled conditions or manually. Most adhesive application is automatic. In one case, a special payout device was built to test dispensers to over 1,000 feet per second payout speed. Normal payout tests are limited to 100 feet per second from a personnel safety standpoint.

Plans are in effect for obtaining larger cable winding machines that will handle cable diameters from 0.2 inch to 0.5 inch.

8.2.4 Prototype Fabrication

The Prototype Fabrication Shop covers an area of approximately 17,000 square feet and is equipped with an array of modern machine tools and sheet-metal-working including lathes, milling machines, grinders, drill presses, rolls, brakes, shears, and a high-precision jig borer. Arc, gas, and Heliarc welding equipment; heat-treat equipment and ovens; a 10-ton overhead crane; and test and environmental test equipment are installed, including an underwater test tank. A large assembly and test area and a separate wire-coil winding facility are also available.

8.2.5 Electronics Laboratory

The Electronics Laboratory is equipped with electronic and test equipment for the performance analyses of complex electronic and electromechanical hardware and devices such as data gathering instrumentation, analog-to-digital and digital-to-analog converters, magnetic and paper tape records, binary-to-decimal conversion equipment, data transmission, timing, countdown, digital training devices, memory systems, automatic checkout, modular boards, transmitters and receivers and radar monitoring.

8.2.6 Environmental Facility

The Environmental Facility includes a 60,000-pound capacity Universal testing machine, a vacuum chamber, and a temperature and humidity environmental test chamber.

8.2.7 Metrology Laboratory

The Metrology Laboratory has participated in the Bureau of Naval Weapons Calibration program since 1959. It maintains a double-wall, solid-shielded room for interference-free electronic calibration and testing work. Its precision standards, which include AC voltage standards from 0.5 to 1500 volts, AC current standards from 7.5 mA to 100 amperes, DC voltage from 0 to 1500, DC amperage from 0.00001 to 300, DC resistance from 0.00001 ohm to 1111 megohms, inductance from 1 microhenry to 1000 henries, capacitance from 0.1 mmfd to 1100 mfd, frequency from 10 Hz to 100 MHz, and temperature from -30° to 408°C, are periodically certified by BuWeps Eastern Primary Standards Laboratory. The Facility regularly calibrates and repairs the Laboratory's production instruments, and also supplies calibration services to NASA and other agencies.

APPENDIX A

HYDROPHONE SPACING OPTIONS (U)

(U) A.1 Introduction

(U) This appendix treats the selection of element spacings in both the horizontal and vertical directions for the Acoustic Test Array. Spacing options include separations between adjacent hydrophones which 1) are uniform, 2) vary in an arithmetic or geometric progression, 3) vary in a random or pseudo random manner, and 4) employ more than one type spacing, sometimes called permutations or hybrid designs. References 8 and 9* and their bibliographies provide a useful guide to beam pattern calculation for hydrophone arrays, while reference 10 gives results for vertical directionality of noise using multichannel delay lines to form beams from a geometrically space-tapered vertical array and a data reduction procedure to select and average data. Reference 11 attacks the problem of the ratio of the peak sidelobe to the main lobe for randomly spaced arrays, where the ratio of the average power to the maximum response tends to 1/N for thinned line arrays.

(U) It is well known that line arrays with uniform spacing have beam patterns that exhibit grating lobes when $d(\cos\theta - \cos\theta_o) = \pm n\lambda$, where d is the spacing between adjacent hydrophones, θ is the standard angle in sperical coordinates with respect to the polar direction, θ_o is the direction of the maximum response axis, n is the order of the grating lobe, and λ is the wavelength of a single frequency incident sound wave Where such grating lobes are undesirable, there are alternatives that may be employed, such as multiple frequency combination techniques (e.g., finite numbers of frequency components or noise bands), multiple beam examination techniques (e.g., deviation loss comparison), non-uniform array spacing techniques (e.g., aperiodic or semiperiodic hydrophone spacing, analogous to amplitude shading), and the brute force uniform spacing technique, where the spacing between adjacent hydrophones is less than half a wavelength at the highest operating frequency.

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*References appear as Appendix I.

(U) Since the aperture of the basic array exceeds thirty wavelengths in the vertical dimension and 150 wavelengths in the orthogonal horizontal dimension at the highest operating frequency, the brute force approach would require upwards of 18,000 hydrophones. This may be reduced considerably to a more acceptable number of hydrophones by limiting the beams to near broadside directions (i.e., $\theta_o = 90°$) and by allowing grating lobes above some specified frequency in the operating band. For a frequency at which the recommended by at least thirty wavelength horizontally, broadside capability is practical for uniform spacing of thirteen vertical by thirty-one horizontal hydrophones, a total of approximately 400. Where it is desired to limit the array, as it is in ATA, to a maximum of ten vertical by eight horizontal hydrophones and a minimum of five vertical by four horizontal hydrophones, further design trade-off is required, especially in the horizontal direction. These limits are arbitrary, but related to maximum data transmission rate, deployment feasibility, seasonal variation of critical depth (sound speed), reliability, and cost, which are not treated in this appendix.

(U) A.2 Vertical Aperture

(U) The vertical aperture is discussed first because the capability of forming satisfactory beam patterns up to the frequency where the aperture is effectively twelve wavelengths is more likely. For uniform spacing, the options of reducing the aperture height to nine wavelengths for the ten hydrophone case or four wavelengths for the five hydrophone case are feasible. This may be accomplished by some combination of reducing the physical spacing dimension or the desired maximum frequency without grating lobes. Before taking one of the above alternatives, a few options with nearly uniform spacing were investigated in this study.

(U) The random or pseudo-random approach was considered as a design guide with the understanding that the array should be designed and not just allowed to happen. The basic result with 90% confidence is that the peak sidelobe to maximum response for a random array of five hydrophones would be between 0 and -1 dB, while for ten hydrophones this improves to between -2 and -3 dB (Reference 11). This suggests that ten hydrophones should be preferred

(U) and a selection of arithmetic and geometric progression spacing designs were considered next, including a hybrid design based on the Fibonacci series. The result for nearly uniform spacing is that there is a noticeable improvement for relatively little deviation from exact uniformity and minor dependence on whether the deviation is arithmetic or geometric. For ease of data interpolation, a symmetrical arithmetic progression was considered with conventional space shading (i.e., narrow spacing near the center) and inverse space shading (i.e., wide spacing near the center). Spacings were in the ratios of 4, 5, 6, 7, 8 with normalization to keep the total vertical length nearly constant. Figures A-1 through A-3 show the comparative results for 0.6, 1.2, and 2.4 wavelength average spacing. With the maximum response at $\theta = 90°$, the maximum sidelobe levels are better than -5 dB for inverse space shading, 0 dB for uniform spacing, and about -4 dB for conventional space shading. The inverse space shading also contributes to an increase in the vertical tracking baseline between the upper and lower half of the array. The limited aperiodicity of the ratios used in the top patterns Figures A1, A2 and A3 can be shown to result in no grating lobes equal to the maximum response until the frequency at which the vertical height reaches sixty wavelengths and a -3 dB side lobe level when the vertical height exceeds thirty wavelengths. While further analysis during the design of the array can be expected to yield further improvement in array behavior, the above analysis is sufficient to recommend a nearly uniform arithmetic progression spacing with symmetrical inverse space shading of ten hydrophones for the vertical configuration of the acoustic test array.

(U) A.3 Horizontal Aperture

(U) Criteria for the horizontal aperture selection are less oriented toward beam patterns and sound speed gradient effects, such as caustics, partly because of the much large linear baseline in terms of wavelengths. The ratio of horizontal to vertical aperture length varies from about 2.5 to 20 for the available options proposed. Also, the number of hydrophones in a horizontal layer has been arbitrarily associated with the aperture length ratio; i.e., 2.5 to 5 for four hydrophone strings and 10 to 20 for eight strings. In either case, the primary objective is to provide data from pairs of hydrophones with a plurality of spacings of different magnitudes suitable for comparison of such properties as cross correlation, although many

(C)

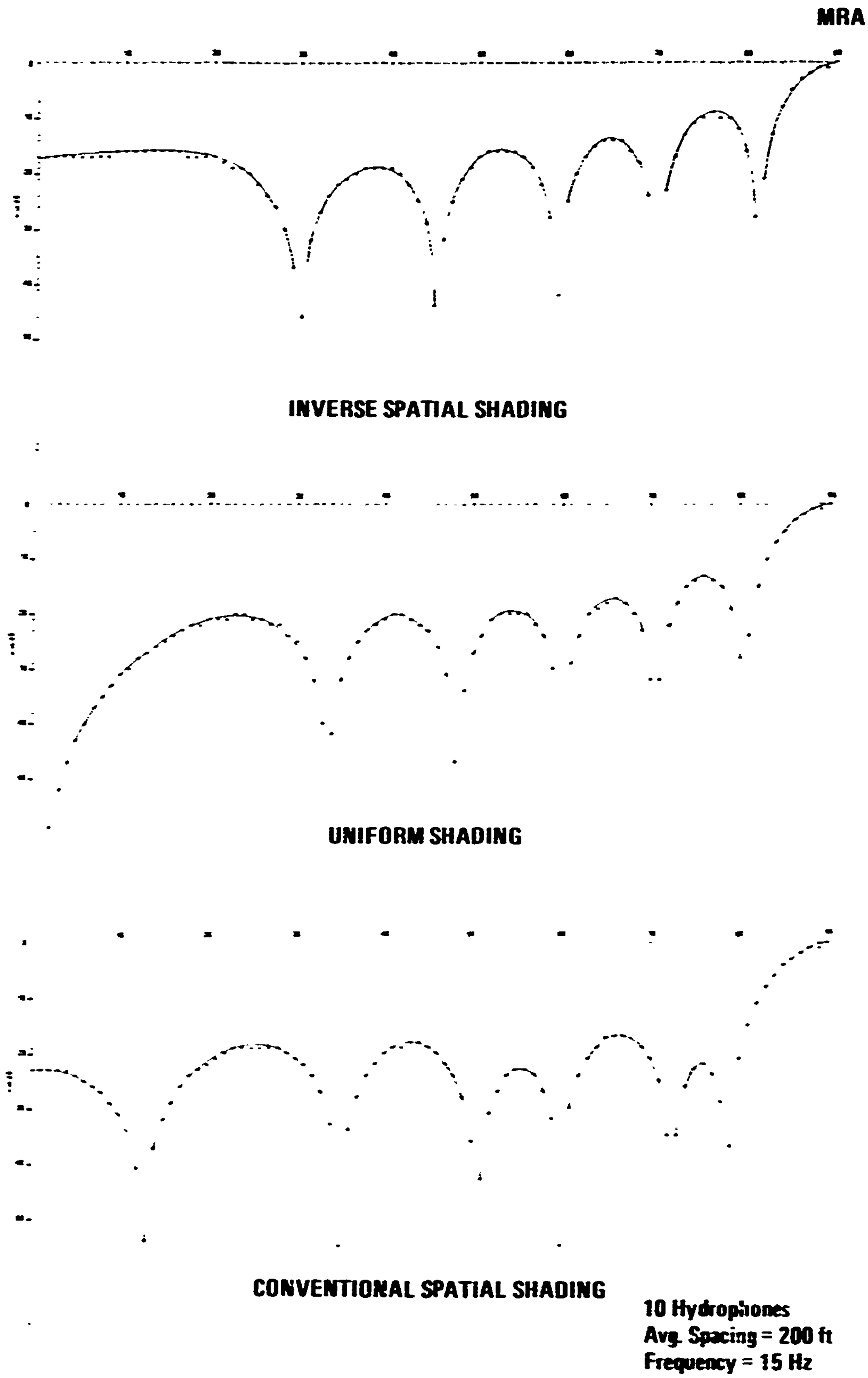

Figure A-1. Vertical Beam Patterns, Average Spacing of 0.6 Wavelength

(C)

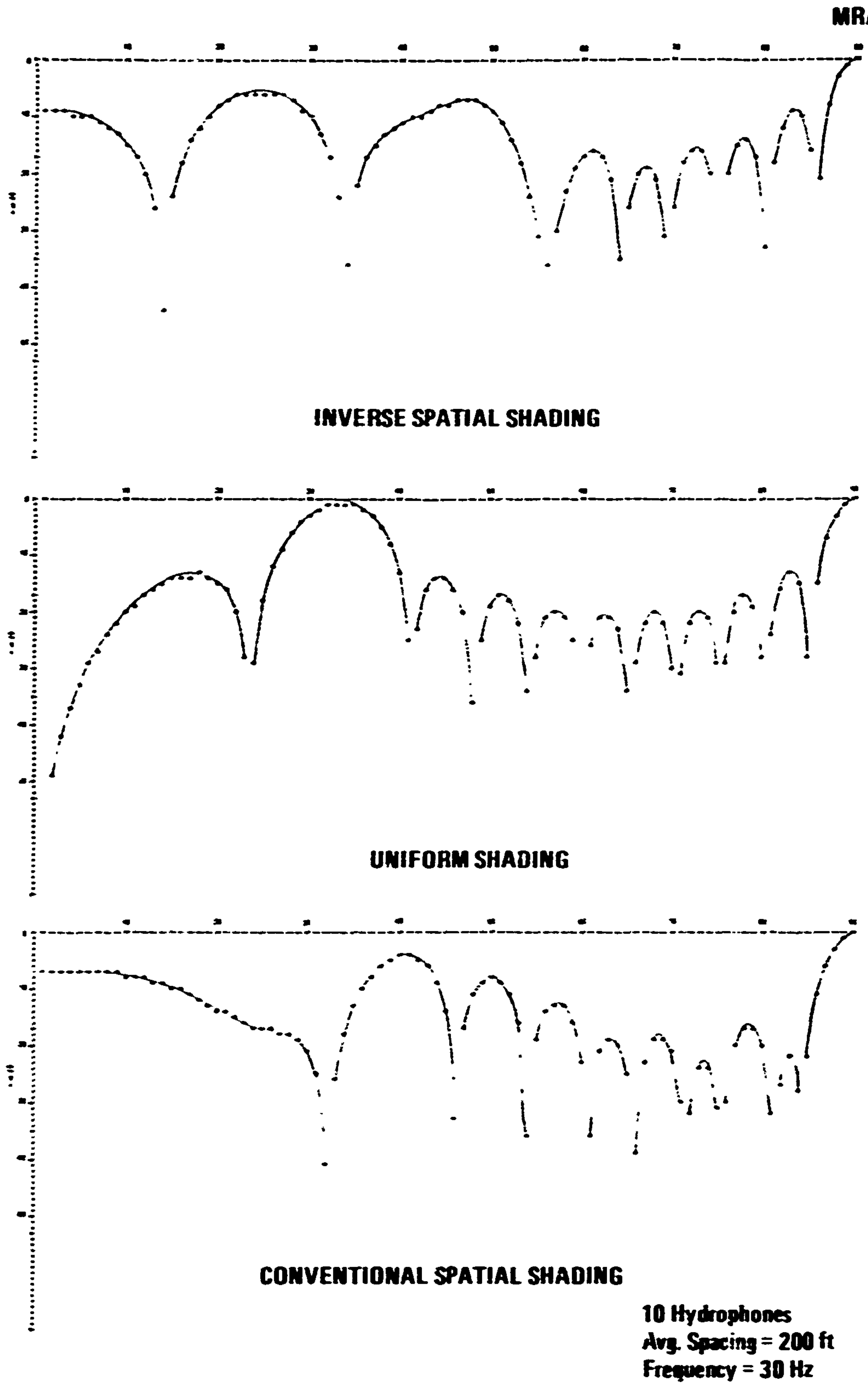

Figure A-2. Vertical Beam Patterns, Average Spacing of 1.2 Wavelength

(C)

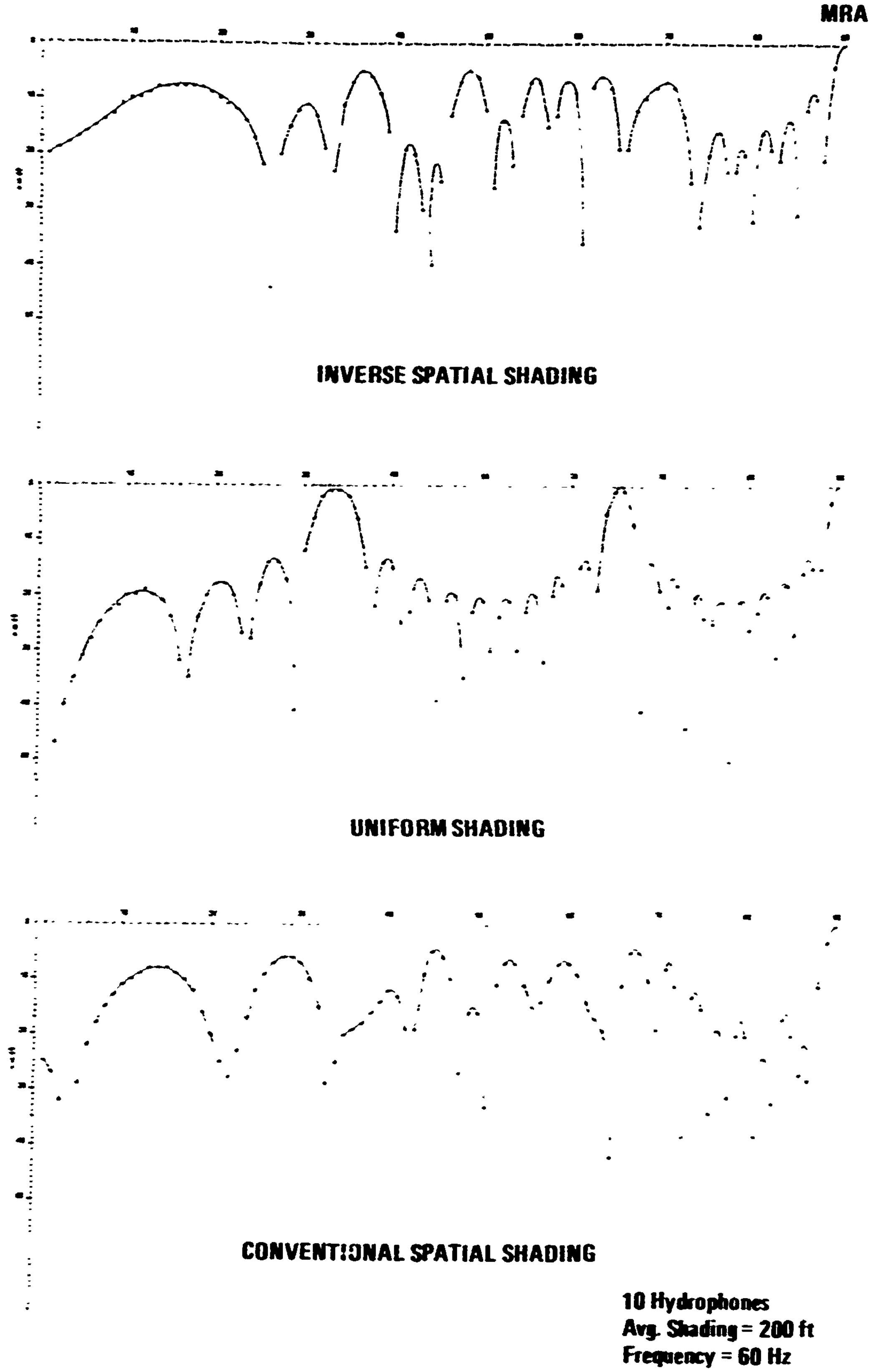

Figure A-3. Vertical Beam Patterns. Average Spacing of 2.4 Wavelength

(U) of the beam pattern considerations for vertical apertures also apply at appropriate frequencies. More discussion on use of the data for measurement and fundamental experiments is given in Appendix B. The above comments and reliability considerations discussed in the section on failure criteria have led to selection of a geometric progression of horizontal spacing between hydrophone strings and an inverse space shading to favor availability of the longer spacings. Beam patterns for the frequencies corresponding to the 0.6 and 1.2 wavelength spacings used in the vertical calculations are given in Figures A-4 and A-5.

(U) Consideration has been given primarily to the extreme cases with the scope of this proposal. The basic system of four hydrophone strings with maximum spacing not less than 5,000 feet tends to limit problems in deploying the first system of its kind as well as cost. The expanded system of eight hydrophone strings with maximum spacing not less than 20,000 feet tends to be more versatile for data acquisition and is ultimately desirable. In either case, an asymmetric spacing configuration is recommended to maximize the number of available spacings. Because successful deployment is a primary consideration at this time, a 5,250-foot, 10-hydrophone string with consecutive linear spacings of 250, 4,000, and 1,000 feet is recommended.

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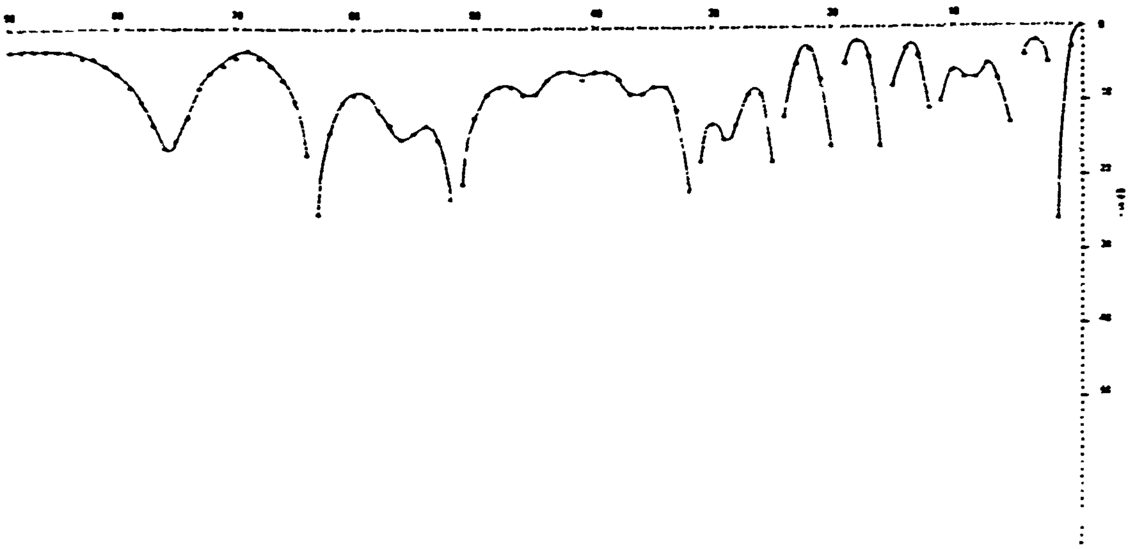
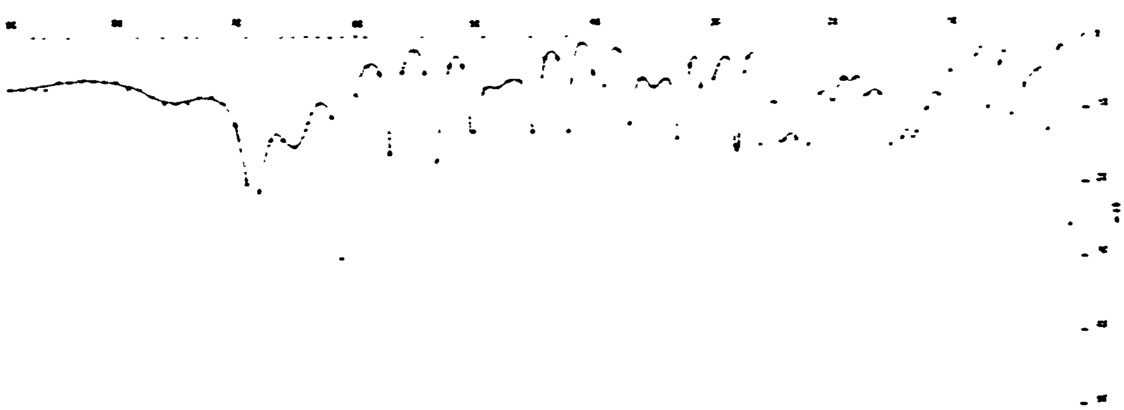


INVERSE SPATIAL SHADING

4 Hydrophones
Avg. Spacing = 1750 feet
Frequency = 15 Hz

Figure A-4. Horizontal Beam Pattern, Average Spacing of 5.25 Wavelength

(C)



INVERSE SPATIAL SHADING

4 Hydrophones
Avg. Spacing = 1750 feet
Frequency = 30 Hz

Figure A-5. Horizontal Beam Pattern, Average Spacing of 10.5 Wavelength

APPENDIX B

MEASUREMENT PROGRAM CONSIDERATIONS AND CONSTRAINTS

Measurement program considerations are of three types: those peculiar to the measurement program, those dictated by hardware constraints, and those common to all signal processing. The measurement program to be formulated may have many nearly independent objectives. Some are among those described in Reference 12, and others are yet to be formulated. The primary demand of these objectives is for a set of hydrophones spaced hundreds of feet apart. Although there is also a use for smaller spacings, hardware constraints limit the array to a few vertical strings of hydrophones, only a subset of which can be simultaneously transmitted to shore via the existing SDC cable. The primary purpose of this appendix is to identify a solution to this problem. The signal processing considerations include data fidelity and provision for multi-hydrophone processing to obtain signal enhancement, bearing estimates, and interference rejection.

Before discussing the need for more than one hydrophone, let us consider the single-hydrophone processing envisioned in Reference 12. The types of acoustic data to be received are noise records, bomb shots and pings. These data are to be used to obtain noise spectra, other sound pressure estimates, and times of arrival. These objectives require omnidirectional hydrophones and associated electronics that are accurately calibrated, stable over long time periods, and capable of reception over a broadband. The system must be linear enough that a loud noise component in a particular frequency band, such as strumming noise, is not smeared over the entire spectrum.

Of the numerous reasons for deploying several hydrophones, two arise from the measurement program. Many of the measurement objectives require hydrophones placed where different propagation or noise conditions exist. For example, hydrophones above and below the critical depth and hydrophones placed to allow comparison of the ambient noise levels at various depths are required. These objectives require hydrophones spaced as far apart as the hardware constraints allow. The measurement objectives also include determination of the spatial properties of ambient noise. When this objective is approached by measuring the

cross-spectrum of the noise as a function of spacing, many different hydrophone spacings are required. When this objective is approached by measuring noise directivity, hydrophone placement that allows beamforming is required. The desired measurements should be obtainable even if some hydrophones fail. Thus, there is a need for hydrophones that are effectively in the same position.

There are four signal processing reasons for multiple hydrophones. First is the desire for signal enhancement relative to the ambient noise. Although it is possible that the sources to be used in the measurements are all loud enough that this is not necessary, it is probable that for some measurements the requirement for adequate single-hydrophone signal level puts an unrealistic demand on source power. Second, the ability to obtain bearing or inclination estimates is desirable in many experiments. Third, the suspension of experimentation when an interference such as a surface ship is near the array is not desirable. Thus, an ability to discriminate between signals and interferences is needed. Finally, the effects of some types of self noise might be eliminated by processing the outputs of more than one hydrophone. For example, some effects of strumming can be eliminated if the strumming noise is uncorrelated along or between strings of hydrophones.

Traditional beamforming is not a satisfactory answer to these demands (Appendix A). The traditional approach to these problems requires an array with sufficient hydrophones placed close enough together to allow formation of narrow beams with low sidelobes. There are several reasons why this is impossible. First, hardware constraints limit the number of hydrophones. Second, the measurement objectives demand wide spacing. Third, the hydrophone strings cannot be placed close enough together for good beams at most frequencies. Fourth, the hydrophones cannot be placed with sufficient accuracy, and their locations may change with time. Fifth, over the wide spacings considered, the wavefronts encountered may not be planar due, for example, to multipath or ray bending. Finally, hydrophone malfunction may cause gaps that make well-behaved beams impossible.

Most of the objectives of multi-hydrophone processing can be accomplished despite the contraint on the total number of hydrophones. What is required are signal processing techniques that are considerably more advanced than the traditional ones. These approaches use hydrophone spacings wide enough and sufficiently irregular to meet the measurement demands.

The signal processing must estimate interhydrophone phase and amplitude relations for signals and interferences instead of requiring that they be specified. A procedure for doing this is being developed with support from the Statistics and Probability Branch of the Office of Naval Research (References 13 and 14). Our simulations show that this procedure can effectively provide signal enhancement, bearing estimates, and multiple signal discrimination without requiring beams with low sidelobes or accurate knowledge of hydrophone locations or signal wavefronts.

APPENDIX C

DETAILED DESCRIPTION OF IMPLANTMENT—ACOUSTIC TEST ARRAY

This appendix to the study provides a detailed description of the proposed method for deploying the system from the cable laying ship and the requirements for facilities to conduct the implant operation.

C.1 System Deployment Method

The method for deploying the system is described in the sequential operations required to implant the system. These operations are: (1) the connection of the SDC cable to the Acoustic Test Array interstation cable, (2) ship's deployment of the substations and anchor on the cable, and (3) system vertical array erection.

C.1.1 SDC Cable and ATA System Interstation Cable Connection

1) With the SDC cable stoppered off or secured to an auxiliary winch by an addition cable, the inshore cable end will be prepared for installation into the junction box. The first reel containing approximately 2,000 feet of ATA system interstation cable will be mounted and threaded through the back tension device (jockey wheel) and the cable engine.

2) Both the inshore cable and interstation cable will then be electrically and structurally connected together inside the junction box. The junction box size will be approximately 5 inches in diameter by 12 inches long, and will weigh approximately 70 pounds.

3) An anchor similar to a Danforth LWT anchor which has a rated holding power in soft mud of approximately 2,900 pounds will be attached to the junction box with approximately 20 feet of 1/2-inch diameter chain. The inshore anchor chain is secured to the junction box with a shear pin and locking device. The anchor will be hoisted to a position ready for deployment over the ship's bow.

4) With the standing end of the interstation cable connected to seawater ground, electrical tests from the shore station will verify the system electrical continuity through the junction box connection.

5) The junction box and inshore anchor will then be lifted and lowered into the water off the ship's bow with a deck crane as the tension is transferred from the SDC cable stopper to the ATA interstation cable held with the cable engine.

6) The anchor will be lowered slowly into the water until the anchor chain becomes taut.

7) The crane attachment to the inshore anchor and the cable stoppers will be removed using a diver. The tension on the interstation cable from the weight of the SDC cable, inshore anchor, and junction box will be approximately 5,000 pounds.

8) The ship will then move forward in the direction of the array field and will proceed to lay the SDC cable and anchor, paying out the interstation cable with the cable engine to lay the SDC cable with a minimum horizontal tension on the ocean floor at a ship's speed of approximately 1 knot. The ship's speed and cable engine can be controlled from the ship's bridge to maintain the required cable tension. The interstation cable will be deployed over the bow sheave under proper tension with the cable engine, passing through the back tension device and spooling off the cable reels.

9) The ship will continue to pay out the interstation cable until the time to deploy the first vertical Acoustic Array Substation. (Shore station electrical tests will continue during deployment but will be temporarily stopped when a substation is inserted in the cable.)

10) Markers on the cable and a reel counter measuring the cable payed out will provide an indication of when the substation is to be inserted. The ship's position and the anchor depth and position from the ship will be periodically monitored and plotted to show the relative positions of the ship, anchor and cable. A dynamometer will measure the cable tension at the cable engine and auxiliary winch.

C.1.2 Ship Deployment of Acoustic Array Substations and Anchor on Cable

1) Substations must be inserted in the cable as the SDC cable and anchor are being lowered to the ocean bottom. When warning markers on the cable indicate the presence of station connectors in the cable, the ship will be slowed and then stopped when the cable terminations approach the jockey wheel.

2) Ship communications to the shore station will be required to stop all testing and remove power on the cable during substation insertion.

3) The cable will be stoppered off forward of the cable engine (high tension side) with a Preformed Line Products Grip on the cable and the shackle in the bitter end of the wire rope from the auxiliary winch. This winch will then take charge of the load.

4) The back tension device will be released and the now slack interstation cable will be slacked off so that it can be released from the cantilevered drum of the cable engine. Prior to slacking the cable, the only significant tension in the cable will be in the length between the stopper and the first wrap on the cable engine. The tension on the cable at the first wrap on the cable engine decreases exponentially for each of the

following wraps until only a relatively low value of back tension is required to keep the system working. In this case, there will be no tension on the reel except for a slight drag from the brake on the reel to prevent jerking or surging.

5) The auxiliary winch will pay out the cable until the stopper is over the bow. The slack section of the cable will be on deck. The end of the next section of interstation cable on the reel will be placed through the fairlead, through the back tensioning device, and around the drum of cable engine by hand until the termination for the cable is located adjacent to previous one. With the crane, the substation will be lifted from its storage rack and set on the deck near the bow.

6) The substation will then be inserted between the cable ends and the terminations secured to the substation. The new section of cable will be applied to the cable engine drum with enough slack on deck to allow the substation to be lowered and submerged in the water. The shore station will be notified to check system performance. With the dummy electrical load placed at the standing end of the cable on the payout reel, power will be applied from shore and system performance verified.

7) Upon verification of the system performance, the auxiliary winch controlling the stoppered cable will be allowed to let the cable engine slowly take the tension on the ATA interstation cable. The auxiliary winch will be slacked off and the crane whip will be slacked. The stopper will then be removed from the interstation cable and the deck crane detached from the substation using a diver. The stopper will remain on the cable for retrieval if necessary. Payout of the cable then continues and the ship will proceed forward at a speed of approximately 1 knot.

8) The ship will continue to pay out the ATA cable until the next substation is to be inserted in the ATA cable. The ship will then be stopped and the same procedure will be used to deploy the remaining substations until the last substation. The last substation will be attached to a seaward anchor via a torque balanced grapnel line. During the payout of cable, the reels of the ATA cable will be carefully identified and stowed in the sequence of use. The cable end on each reel will have provisions to enable the shore station to monitor the portion of the system that has been laid as well as the cable being deployed.

9) When the last substation has been connected to the last section of the interstation cable, the grapnel line will be secured to the opposite side of the substation. The substation will be lowered under tension using the grapnel line in the same manner previously used in deploying the substation with the ATA interstation cable. For the Basic array or the Recommended this is continued until the shore anchor approaches the bottom. After the inshore anchor is placed on the ocean floor, the ship will pay out line to establish a catenary that maintains a 1,000-pound horizontal tension at the anchor. This will be accomplished by maintaining approximately 5,000 pounds tension at the cable engine and controlling the ship's speed and position. For the Expanded array, the inshore anchor will be secured on the ocean floor while the ATA interstation cable is being payed out.

10) After the last substation has been deployed and approximately 2,000 feet of grapnel line have been payed out, the ship and cable engine will be stopped to attach a seaward anchor. The seaward anchor, which is to be a clump type anchor weighing approximately 2,000 pounds in water and constructed of concrete with metal prongs, will then be attached to the stoppered grapnel line. The anchor will be lowered into the water with the deck crane. The cable tension will then be transferred from the auxiliary winch to the cable engine. The cable stoppers and crane attachment will be removed by a diver. The ship then will continue to pay out cable until the seaward anchor reaches the bottom.

C.1.3 System Vertical Array Erection

The final step in the system implant will be the vertical erection of the acoustic arrays from each station. The line attached to the seaward anchor will be dropped after the position of the system on the ocean floor has been determined to be correct and the system is operating properly as verified by the shore station. The grapnel line will be released in a position to avoid any possible interference with the implanted system. Each station, upon command from shore, will erect the array in the required sequence based on measurements and evaluation of the ocean bottom currents.

The horizontal tension component of approximately 1,000 pounds will be applied to the interstation cable during implant to achieve the desired spacing between substations. Sharp increases in the ocean bottom elevation will be considered in the implantment since they can affect the spacing of the array. In selecting the final implantment site, the bottom topography, weather, sea state history, ocean floor environment at the implantment site will be evaluated in detail for the final implantment site, the bottom topography, weather, sea state history, ocean floor environment at the implantment site will be evaluated in detail for the final implantment plan.

C.2 System Implantment Requirements

This section specifies the ship characteristics required for implant and the site and shore base characteristics that must be considered in the implantment planning.

C.2.1 Ship Characteristics

The vessel that is capable of implanting the Acoustic Test Array System must have the required maneuverability and handling characteristics, cable handling equipment, deck machinery, deck stowage and working space, navigation and communications systems, personnel living facilities, and an adequate complement of experienced crew members.

An investigation to determine a ship having the desired characteristics was conducted and a vessel comparable in size, speed, and economy of operation with the Army FS or Navy AKL conversion that can be modified with the required cable handling and deck machinery was considered suitable for performing the operations required for the ATA system implantment. The R/V F.V. HUNT owned by TRACOR MAS has the ship characteristics to meet the system implantment requirements.

C.2.1 Ship Maneuverability and Handling

The implant vessel should have the following minimum maneuvering and handling capabilities to implant the ATA system:

- Maintain course along a preselected track within ±250 feet.
- Velocity control in increments of 0.1 knot to ±3 knots, with the ability to heave to.
- Maintain a heading within ±1.5 degrees under the following maximum environment:
  - Sea State—3
  - Wind Velocity—20 knots
  - Current Velocity—4.5 knots (This current may not be realistic for the site. A current survey should be made prior to implantment, possibly during the training phase, and a cable track selected that would offer the least problems during implantment; e.g., the ship headed into predominant sea conditions or track with few cross currents.)

The R/V F.V. HUNT has an overall length of 185 feet, an extreme beam of 35 feet, and a laden draft of 11 feet, 6 inches. The ship's diesel-electric propulsion system, consisting of two 500-hp Winton engines, drives a series of four direct current generators. These generators, in turn, drive an electric motor (560-hp capacity) on each of two shafts. Propeller shaft speed is variable from 0 through 230 rpm and is directly controlled from the wheel house and two remote stations.

Exceptional maneuverability is obtained from the diesel-electric propulsion system and the ship's bow and stern thrusters, each rated at 150 hp. Use of screws and thrusters permits the vessel to turn in its own length. The R/V F.V. HUNT can maintain a position in a 1.5 knot beam current using only the bow and stern thrusters. In higher currents, the main engines and thrusters would be used to hold the ship on station at an angle to the current. Precise maintenance of station under the conditions of wind and ocean current required can be achieved.

The ship is capable of a cruising speed of 10-11 knots and normal fuel tanks provide a cruising range of 10,000 miles. Fuel consumption is approximately 100 gallons per hour.

The primary power sources for all purposes are two 200 kW, 400 V, three-phase, 60 Hz, diesel-driven alternators. Power from these alternators may be transformed to any single-phase or three-phase voltage required. At most times, at least 50 kW of ac is available for scientific use. One hundred kW of 120 Vdc is available on a shared basis.

C.2.1.2 Crew and Berthing Provisions

The crew complement of 17 is experienced in a wide variety of deep water cable laying projects. Quarters are available for up to 14 additional personnel.

Fresh water tankage is in excess of 11,000 gallons and, in addition, 1800 gallons of fresh water per day are made by the evaporators. Walk-in refrigerators and freezers, in addition to reefers in the galley, store sufficient perishable foods to permit cruises of 45 days with a full complement.

C.2.1.3 Cable Handling Equipment and Deck Handling

The ship must be modified to add a hydraulic drive cable engine, back tensioning device, auxiliary constant tension winch and bow sheave for paying out the ATA interstation cable. The system must be capable of measuring and handling cable tensions of up to 7,000 pounds at a payout speed of 200 feet/minute. The system must include instrumentation and load cells to accurately measure the cable footage that has been payed out and the tension on the cable at all times.

The ship is equipped with an Austin-Western 410-P crane with a 23-foot boom extension mounted on the fore deck. This crane can lift up to 12 tons and is ideal for hoisting and lowering substations and anchors over the side plus deck handling the cable reels. Other hoists and handling gear are available on the fore deck which has an open deck area of approximately 800 square feet.

C.2.1.4 Communications and Electronic Navigation

The R/V F.V. HUNT is equipped with the following systems:

- Radar
  - One 75 kW RCA Model CMR-N1A-75 "X" band
  - One 30 kW RCA Model CMR-N2A-30 "S" band
- Radiotelephones
  - Two Konigsberg Model DR-200, 2 to 8 MHz, 11 channels, 200 W input
  - One Konigsberg Model DR-200HS, 4 to 18 MHz, 11 channels, 200 W (as above)
- Radio Direction Finder
  - A Bendix Model 162 Automatic Direction Finder mounted in the wheelhouse
- Loran
  - An RCA Model LR 8803 Loran is mounted in the chart room
  - A radio receiver to receive time and frequency standard signals from WWV is furnished.

A Decca Hi-Fix navigation system may be required to accurately determine the location of the implanted system.

C.2.2 Operational Site Characteristics

The operation site must be investigated and the following information obtained for the system implantment:

- Weather and sea state history including storm data, seasonal wind and sea state data, air and water temperature extremes

- Area and water depth, bottom topography and conditions, sea current profile and temperature variations
- Operational area testing and deployment restrictions
- Navigational aids for system positioning and navigational hazards in the area.

C.2.3 Shore Base Characteristics

The shore base which will be used as a preparation area during the training and testing phases and a loading area for final system implantment will require investigation of the following characteristics:

- Available docking, repair, storage, communication and weather facilities including logistic support facilities such as airports
- Security limitations in the area
- Transient housing for implantment personnel
- Tide and current data
- Area accessibility for personnel and ships
- Cranes, forklifts, trucks for equipment refurbishing, maintenance and ship loading including the availability of general ship maintenance equipment and marine supplies.

APPENDIX D

CONSULTANT (TRACOR MAS) CRITIQUE OF SYSTEM IMPLANT PLAN

D.1 Introduction

This appendix contains the response of TRACOR MAS to the Vitro request to review and evaluate a proposed plan to implant the Acoustic Test Array System and to discuss the required ship handling characteristics. TRACOR MAS was requested to critique the proposed concept in view of their cable laying capability and familiarization with a variety of cable laying ships applicable for the implantment of the Acoustic Test Array.

TRACOR MAS has presented their general critique and implantment considerations in the first four sections of their attached enclosure. Sections 5 through 10 are responses to questions generated by Vitro for special consideration. The questions that were proposed to TRACOR MAS were:

5. The implant method utilizes cable terminations that are attached to the substation during system deployment. Can the cable and terminations be passed through the cable payout device and be deployed with the substation package without damage? Can the cable laying ship maintain constant tension on the cable while the substations are being attached to the cable ends? Is there sufficient space for stowing the substations near the cable payout devices?
6. Figure 3 of the Vitro proposed plan shows the deployment method for implanting the system. What technique should be employed for laying the SDC cable with zero tension at the ocean bottom and is the 1,000 pound horizontal tension on the interstation cable considered adequate to maintain the substation spacing? What safety factor on the interstation cable breaking strength is required for implanting the system?
7. Sequential deployment of the vertical arrays from adjacent substations is being considered. What effect will the ocean current have on the erection of the arrays?
8. Using the implantment method described, are there any special techniques required during cable payout to maintain tension in the interstation cable when the shore anchor reaches the ocean bottom?
9. What anchor configurations are recommended for this application in deep water having a sand or silt ocean bottom and what techniques are recommended for minimizing the anchor weight on the interstation cable?

10. Is there a computer program available to perform both static and dynamic load analysis on the interstation cable considering point loading and catenary variations under different sea-state conditions?

Quoted here is a letter concerning the ATA System implant plan from Mr. M. Lowell Collier, Director of Engineering (Acting), TRACOR/MAS to Mr. R.P. Mohr of Vitro.

Dear Mr. Mohr:

TRACOR/MAS has reviewed and evaluated the concept for the installation of the Acoustic Test Array System. This array can be implanted using standard cable-laying techniques. Our critique and recommended techniques for installing the system are presented in Enclosure 1.

A ship such as our R/V F.V. HUNT is recommended for the training and implantment of the array. The general specifications on this ship are enclosed with a discussion of the ship-handling characteristics in the sea states and currents specified.

Very truly yours,

M. Lowell Collier
(Acting) Director of Engineering

D.2 Acoustic Test Array Implantment Considerations

1. For the type of deployment shown, a typical ship might be an off-shore supply boat of about 150 foot length. However, for the accuracies required in the sea states called out, a ship built for cable laying is recommended. There are several cable laying ships that might be available for charter, but for this exercise we can use the R/V F.V. HUNT Cable Layer owned by TRACOR/MAS as an example. This ship can keep station using its bow thrusters at a speed of one knot. For the accuracies specified here, additional navigational equipment such as a Decca Hi-fix with powered shore stations may be required. It is felt the ship can maintain station within a 500 foot corridor under conditions stated in Enclosure 1.

   With this ship the cable could be stored on reels on deck. The cable would then pass over a jockey wheel to a hydraulic powered cable engine, and the cable then deployed from the bow sheave on the boat. The jockey wheel is required to maintain back tension on the cable engine. This is a standard cable laying technique.

Whenever a substation or anchor is added into the cable line the cable would be stoppered off forward of the cable engine (high tension side). It is recommended that cable stoppers such as the PLP type be installed in the line at the point near where a substation or anchor must be attached. After the cable has been stoppered the cable can be removed from the cantilevered drum of the cable engine and substation or anchor inserted. This presents no problem with torque-balanced cable.

The SDC cable should be layed with approximately 5 percent slack; i.e., cable pay out rate 1.05 times ship velocity. This eliminates the possibilities of any cable suspensions on the ocean bottom. Likewise the cable engine pay out rate can be slowed to less than ship velocity for laying cable with a predetermined tension at the bottom end.

2. In cable laying,a ship Fathometer* is used for bottom survey ahead of the cable touchdown point. When changes in bottom contour are noted on the chart recorder, the time when the cable will reach that point is calculated and changes in cable payout rates programmed for that time.

   The simplest way to indicate when the anchor has reached bottom is to monitor tension by passing the cable over a snatch block load cell arrangement and noting when the tension suddenly drops. We have never used pingers attached to anchors or other pay loads for indicating bottom contact. However there are many self-powered pingers on the market that could be attached to the anchors or substation and the depth of the device detected with a hydrophone. This depth can then be compared with the fathometer reading. The accuracy, however, would be poor. More exotic devices could be made, but they are not generally used in this type of application because of expense.

3. The reels of cable would be stored on the foredeck, and since the cable is stoppered at the bow sheave no problem would be anticipated in changing from one reel of cable to the next. It would only be necessary to fairlead the line through snatch blocks to the back tensioning sheave. A motor chain drive could be used to rewind the cable on the reels during recovery.

4. Assume the interstation cable is being deployed under the proper tension with the cable engine, passing through the back tension device, and spooling off the cable reel. Stop the winches and stop the ship. Secure a stopper (Preformed Line Products type) on the cable under tension forward of the winch and shackle in the bitter end of the wire from the auxiliary winch. With this winch, take charge of the load. Release the back tension device and remove the now slack cable from the cable engine. The only significant tension in the cable is, or was, in the length between the stopper and the first wrap on the cable engine. From this point the tension decays exponentially for each wrap until only a relatively low value of back tension is required to keep the system working. In this case there is no tension on the reel except a slight drag from the brake to keep the reel from jerking or surging. Pay out on the auxiliary winch until the stopper is over the bow. The slack section of cable is on deck. By hand, fairlead the next section of cable from the reel, through the back tension device and around the sheaves of the cable engine until the end termination is lying adjacent to the previous one. With the crane, lift the substation from its storage rack and set

*Raytheon trademark

on deck near the bow. Make up the end terminations to the substation. Using the crane, deploy the substation over the bow. Pay out on the auxiliary winch until the cable tension, or load, is taken by the cable engine. At the same time, hold the substation with the crane so that it becomes part of the "in-line" load on the cable. Slack off the auxiliary winch and slack off the crane whip. A diver will now release both the winch wire from the stopper and the crane whip from the substation. The stopper will remain on the cable for retrieval if necessary. Continue paying out with the cable engine as before. A well-designed, torque-balanced cable should not hackle under these conditions, but tests should be performed before installation. Shore to ship testing will take place as required during these operations.

5. The end terminations would have to take the load of seven thousand pounds, and a slight kink may develop due to the concentrated load of the package. In selecting the ship, deck space to stow equipment is one of the primary requirements. Using a cable engine with the cable stoppered at the high tension side, the end termination never passes around the drum. The auxiliary winch can be operated under constant tension control if desired to compensate for ship motion.

6. In Figure 4-2 the SDC cable is shown being layed with curvature in the cable. This is a "List 1" cable, and if layed with zero tension at the bottom the cable is a straight line between the bottom and the ship. A List 1 cable has an H factor of approximately 35 degree-knots, or at one knot the angle between the horizontal would be 35 degrees. The one thousand pound tension on the interstation cable is probably adequate to maintain the spacing. However, the total tension in the cable at this point should represent a factor of safety of at least 3 (preferably 4) on the breaking strength of this cable. Installation should not be attempted with a factor of safety less than 3.

7. Simultaneous erection would prevent two stations becoming tangled, but it would be easier to monitor a sequential deployment. If deployed in sequence the current speed and direction should be measured and the down stream unit deployed first. Shear currents in the last 1500 feet of the bottom could present problems.

8. No problems are anticipated if the tension in the lower part of the cable is momentarily relaxed when the shore anchor touches bottom. Once the anchor is set the new relationship between the ship velocity and cable payout will insure the required tension.

9. Simple clump anchors are usually suitable for preventing submarine cable from migrating. They have a horizontal holding power of approximately 1/2 their water weight. In sand or mud bottoms this is increased as the clumps are silted in. The holding power can be improved by adding spikes or steel feet when the concrete is cast. Another method is to add a light mushroom or Danforth anchor to a length of chain secured to the clump.

   When the water weight of the clump is such that the safety factor in the submarine cable is below recommended limits a float or other form of buoyancy can be secured to the clump to reduce the negative buoyancy during lowering. This float can be acoustically or otherwise remotely released after touchdown to restore the full water

weight of the clump. Another technique that would accomplish the same purpose would be a clump with a floodable compartment activated after touchdown.

10. Both a static and dynamic analysis can be performed to determine maximum loads in the cable. The most critical dynamic loads would occur when the array is vertical and the lower anchor is not on the bottom. Our dynamic analysis program will predict tension and motions of an N degree of freedom spring mass system. The cable and masses are assumed to lie in a straight line.

    The static analysis is used to calculate the catenary configuration of the cable and masses during deployment from the ship. Our program can handle N cable segments of any mass and length. Point loads on the cable can be considered and tensions at any point calculated. This program can be used to predict tension at the ship to ensure the array is layed taut.

D.3 Ship Handling Characteristics

With regard to the ship operating requirements, the following comments are made:

1. A ship such as R/V HUNT can maintain a track within ±250 feet. However, in the presence of strong ocean currents the cable may not stay within this corridor.
2. The 4.5 knot current may not be realistic for the location. A current survey should be made prior to installation, possibly during the training phase, and a cable track selected that would offer the least problems during the installation, e.g., ship headed into predominant sea conditions or track with few cross currents.
3. The R/V HUNT can maintain position in a 1.5 knot beam current using only the bow and stern thrusters. In higher currents the main engines and thrusters would be used to hold the ship on station at an angle to the current.
4. A heading of ±0.5% probably could not be maintained with weather on the quarter. Even in head seas as the ship pitches, it may fall off more than .5°.

APPENDIX E

INTERSTATION CABLE DESIGN CONSIDERATIONS

The design of the interstation cable and the deployment method for the Acoustic Test Array System are interdependent and trade-offs in both areas must be considered.

The design approach followed for the interstation cable provides a high strength coaxial cable (15,000 lb. breaking strength) that will adequately support the SDC cable, the inshore anchor, junction box and substations during implantment of the system using the interstation cable and one cable laying ship. The implantment technique described in the study can utilize the same ship to implant the system that retrieves the SDC cable.

Other alternate concepts were considered that would utilize a low strength (10,000-pound breaking strength) and less costly interstation cable but the resulting implantment method required a ship to deploy the Acoustic Test Array System and another ship to support the SDC cable and inshore anchor with a grapnel line until the cable and anchor are layed on the ocean bottom.

A technique that was considered in using the low strength interstation cable started by laying the Acoustic Test Array Systems from the seaward end of the array using a lightweight sea anchor. The interstation cable would use a low strength construction that would only be required to support the anchor and system components. The system would be implanted by one ship that would rendezvous with a second ship that has retrieved the existing SDC cable. The interstation cable would be passed to the second ship which would perform the connection between the SDC cable and the Acoustic Test Array. After testing by the shore station, the second ship would then lay the SDC cable, anchor and interstation cable on the ocean bottom. This implantment technique does not permit the acoustic test array performance to be monitored during its deployment by the shore station. Any abnormalities would not be discovered until the system had been implanted unless the required shore station equipment could be duplicated on the deployment ship.

The design approach to use a high strength interstation cable and the implantment technique described utilizing only one ship is considered to be optimum. The technique enables the system to be implanted within the required system accuracies. The overall implantment and cable tensions can be controlled with reduced complexity using the one ship. The additional cost resulting from using the high strength cable ($0.870/ft.) rather than the low strength cable ($0.613/ft.) is $1,867 for the basic system and $6,100 for the expanded system. This cost would be more than offset by the cost of an additional ship, and the additional communication and rendezvous problems.

APPENDIX F

VERTICAL CABLE TECHNICAL CONSIDERATIONS

The substation anchor, its suspended vertical array cable, and float have been investigated as a deep sea mooring system. Investigation of the system considered the mean bottom current, maximum bottom current, vertical current profile, in-water weight and horizontal drag of the submerged elements. Based on the current velocities at the implant site, the characteristics of 1/4" outside diameter, 8-conductor vertical array cable weighing approximately 30 pounds/1,000' in water were compared to a larger 16-conductor vertical array cable, .50 O.D. weighing approximately 50 pounds/1,000' in water. The larger cable with its additional conductors provides redundant B+ power and B- return conductors for alternate hydrophones from the redundant substation electronic systems, plus an additional sensor cable. Flooding of either a hydrophone or its preamplifier will not disable a substation with the larger cable. This trade-off was examined for both the Basic and Expanded systems based on an average current velocity of .05 knot at the ocean floor, increasing to .08 and .09 knot, respectively at th   :hs of the floats for the Basic, Recommended and Expanded systems.

The vertical arra; orizontal drag forces, due to current, were determined for both cables using the computation for drag forces and drag coefficients outlined in reference 15. The vertical forces on the cables were then computed based on a minimum vertical array cable tension of 50 pounds. The array cable angle at the anchor and the float excursion were estimated as outlined in reference 15. The estimated array cable angles were less than 2-1/2° for the cables investigated. The vertical array excursion was also investigated and appears to be more meaningful in depicting the effects of the various cable configurations. The excursion of a subsurface buoy is the horizontal displacement of the buoy due to current from a true vertical array axis. The float excursions for the basic and expanded systems are less than 7 feet and 38 feet respectively for the 1/4" diameter cable and approximately 17 feet and 49 feet respectively for the larger cable. The larger cable is recommended. While requiring a larger substation package, it provides adequate vertical array stability with increased system reliability.

APPENDIX G

LIST OF GOVERNMENT FURNISHED FACILITIES AND MATERIAL

The following government furnished facilities, equipment and services are required to perform Phase II, the design development, test and implant of an Acoustic Test Array:

Item	Description of Equipment and Services	Weeks Required After Contract Start
A	Ship and associated services to recover existing SDC cable and verify integrity.	5
B	Ship and associated services to attach and implant substation test unit on end of SDC cable.	10
C	Shore station testing services to periodically monitor performance of implanted substation test unit at Bermuda Tudor Hill station.	10 thru 26
D	Ship and associated services to retrieve implanted substation test unit.	25
E	Shore base facilities consisting of 1,000 sq. ft. minimum space with office, laboratory, storage and docking facilities. Facilities shall include dockside handling equipment (crane and forklift, etc.) and trucks for transporting acoustic test array equipment between freight terminal, shore base and dock.	
	Shore base required for at-sea developmental tests in Florida area.	20 thru 26
	Shore base required for training and implant in Bermuda.	33 thru 40
F	Temperature test facility at Naval Ordnance Laboratory, White Oak, Md. or equivalent.	14
G	Vibration test facility at Naval Research Laboratory, Washington, D. C. or equivalent.	15
H	Hydrostatic pressure facility (10,000 psi capability) at Naval Ship Research and Development Center, Carderock, Maryland.	16

Item	Description of Equipment and Services	Weeks Required After Contract Start
I	Ship and associated services, with ship characteristics and cable laying capability as defined in Feasibility Study Appendix, for the conduct of developmental system testing in deep and shallow water off the coast of Florida.	20 thru 26
J	Small craft (YF type) for deep and shallow water developmental vertical array payout tests off coast of Florida.	22, 23
K	Cable laying ship and associated services with ship cable laying characteristics facilities as defined in the Feasibility Study Appendix for training, implant tests and system implant.	32 thru 40
L	Transportation of Acoustic Test Array system equipments and support equipment from Submarine Signal Division, Portsmouth, R.I. to all test sites (beyond 70-mile radius), from Vitro Laboratories, Silver Spring, Md. to all test sites (beyond 70-mile radius) and from either to the ultimate destination.	9 thru 40

APPENDIX H

BIOGRAPHIES OF KEY PERSONNEL

WILLIAM CIBOSKY, Program Manager, Submarine Signal Division

EDUCATION: B.S., U.S. Military Academy, 1958; M.S. (Applied Physics), Stevens Institute of Technology, 1964; graduate work (Engineering Management), Northeastern University

BACKGROUND: Mr. Cibosky joined Raytheon in July of 1972 and has been assigned responsibility for fixed sonar and signal-processing systems within the Advanced Design business area.

His previous position was with the AVCO Systems Division (1966—1972), where he assumed management responsibility for the Air Force's Mark II series reentry vehicles R&D programs.

Prior to joining AVCO, Mr. Cibosky's military assignment was with the NIKE-X Program. During this time he monitored and supervised contractor efforts at field sites and test ranges. Mr. Cibosky retired from the Army in 1966 due to a service-connected injury.

STANLEY L. EHRLICH, Consulting Engineer, Submarine Signal Division

EDUCATION: B.S.E.E. and M.S. (Physics), Brown University

BACKGROUND: Mr. Ehrlich has been with Raytheon since 1953 and is currently Technical Director for several system development programs and Staff Specialist for airborne systems, transducers, and arrays in the System Engineering Laboratory. Previously, he held the positions of Technical Director of Advanced Shipboard Programs, Technical Director of AN/BQQ Programs, Principal Sonar Systems Engineer, Product Line Manager of Airborne Sonar and Countermeasures, Section Manager of Airborne Systems, and Senior Sonar System Design Engineer. In these capacities, Mr. Ehrlich has conducted research on magnetostrictive and ferroelectric material and co-invented the first underwater swimmer's telephone transducer at USN/USL; developed LOMASS and AN/AQS-6 (XN-2) arrays; co-invented a multimode system and transducer applied to AN/AQS-13 and AN/WLR-5; conceived and/or technically directed many sonar system developments for AN/BQS-6, Acoustic Switch, AN/AQS-8, KUBA/WSU/WSZ, AN/BQS-11, -12, -13 and related programs, and precision-scale modeling of transducer arrays and domes. Several of these systems are dipped, towed, or air-launched from helicopters or fixed-wing aircraft.

Mr. Ehrlich has published over a dozen articles in journals sponsored by the Acoustical Society, Underwater Sound Advisory Group, and IRE/IEEE. He has translated (with a co-author) a book on "Fundamentals of Electroacoustics," and has been issued five patents with others still pending.

HERBERT C. SINGLE, Manager, Design Engineering, Submarine Signal Division

EDUCATION: B.S.E.E., Northeastern University; various graduate studies

BACKGROUND: Mr. Single joined the Submarine Signal Division in 1960. Currently, as Manager of Product Engineering, he is responsible for planning, organizing, staffing, and directing departmental activities in the development and design of ASW equipments and components. Previously, he served as Assistant Manager. Earlier, as a Section Manager, he was responsible for electrical design in sonobuoys, transponders, airborne receivers and indicators, ECM equipment servos, modular drivers and solid-state inverters, magnetics, miniaturization, and spectrum analyzers. As a group leader, Mr. Single provided analytical and experimental electrical data for the design of sonar systems. He was responsible for the electrical design of circuits in Raytheon's recent helicopter-dipped sonar, the AN/AQS-12, and for a lightweight helicopter system utilizing digital techniques and microminiature components in order to reduce weight and increase performance.

Mr. Single has designed both tube-type and transistorized depth-sounding equipments for commercial use. He is the author of various articles on depth-sounding devices and is a registered professional engineer in Massachusetts.

As Manager of Product Design, Mr. Single is also responsible for such contracts currently being performed by Raytheon as the Mk-27 design review, AN/BQN-17, AN/BQR-19, DE-1160 small-ship sonar, and various transducer programs.

ROBERT B. DELISLE, Associate Engineer, Electrical Design, Submarine Signal Division

EDUCATION: B.S., Rensselaer Polytechnic Institute; M.S., Rensselaer Polytechnic Institute

BACKGROUND: Mr. Delisle has been with the Submarine Signal Division for 2 years. During this time he has been involved in both analog and digital design. Presently, he is involved in the design of the preprocessor for a real-time spectrum analyzer and, in the past, has been involved in the design of a digital PDPC receiver and a digital acoustic intercept receiver.

Mr. Delisle is a member of Tau Beta Pi and Eta Kappa Nu engineering honorary fraternities.

RALPH P. MOHR, Senior Engineer, Development Engineering Department, Vitro Laboratories Division

EDUCATION: B.S.M.E., University of Maryland, 1953

BACKGROUND: Mr. Mohr has been with Vitro since 1955. He is currently directing the group performing the feasibility study for the Acoustic Test Array. He has previously directed the effort of a mechanical engineering section that designed, fabricated, and tested a pod handling system for Torpedo Mk 48; directed a mechanical interface coordination effort for Torpedo Mk 48, involving the analysis of loading and handling problems; directed the effort of a mechanical engineering section involved in the design of a Fiberglas spar buoy and launching system capable of launching a buoy from a submarine; prepared the coordination drawings for the optical alignment system on the POLARIS FBM submarines; prepared the system tests for checking optical system alignment; and devised special test equipment to verify that the submarine optics were within system requirements.

In addition, Mr. Mohr served as Group Supervisor (1962—1965) providing engineering services for Torpedo Mk 37 Mod 0 and Mod 1 and design cognizance for Torpedo Mk 37 Mod 1. The engineering services performed consisted of modification to torpedo control circuits, investigation of electrical noise sources and noise reduction, and revisions and updating of OPs. Design cognizance services included monitoring the design through full-scale production at NOPF, providing assistance through Phase I and Phase II proofing at NTS, Keyport, and providing formal training classes in torpedo theory to Navy instructors.

Prior to 1962, Mr. Mohr served as a section leader responsible for the design of the prototype hull section and handling and workshop equipment for Torpedo Mk 37 Mod 1. He has worked on the preliminary design of the HIDENT torpedo and designed and tested a pressure vessel for an ocean-floor repeater.

While in the U.S. Air Force, he supervised an aircraft field maintenance shop, performing major overhaul and repair of aircraft communication equipment.

Mr. Mohr is associated with the Sea Horse Institute.

RICHARD R. CANNON, Development Engineer, Vitro Laboratories Division

EDUCATION: B.S.M.E., University of Delaware, 1961

BACKGROUND: Mr. Cannon has been with Vitro since 1961 and was involved in a program for the design, development, fabrication, and test of a submarine-launched buoy electronic system. He was responsible for the system field installation and evaluation; participated in the design and development of the initial system and was responsible for the conduct of system evaluation, extensive environmental (temperature, vibration, and shock) and qualification testing that was performed at several government laboratories and at sea; was responsible for the design and development of a Training System for the buoy electronics system; has performed a study to determine workshop areas for equipment preparation and developed various concepts for handling the equipment; and has worked on the electromechanical aspects of Buoy Launching Control interfaces and a compressed-air-type launcher. Mr. Cannon is experienced in the design and packaging of servomechanisms and in developing overall packaging concepts for console and display equipments. He was responsible for the design of a postal service spiral chute and retractable container loaders for sacks and parcels. (The chute, which uses modular construction techniques, has a curved bottom design that was developed to achieve a relatively uniform parcel velocity.) Design of the chute slide material required the investigation of numerous materials for low friction and high-wear characteristics as related to the various materials found in the postal system and development of chute fabrication techniques that can be economically produced. The retractable container loaders are designed for semiautomatic operation with a minimum of mail damage. The loaders required the application of reliable and durable mechanism designs and electromechanical switching functions.

Prior to coming to Vitro, Mr. Cannon worked on system design, development, and test of an airborne reconnaissance system. This involved the design of lightweight structures for electronic equipment to withstand severe vibration and temperature environments. He also worked on the manufacture and modification of airborne radars and computers.

WILLIAM R. TAYLOR, Engineer, Development Engineering Department, Vitro Laboratories Division

EDUCATION: B.S. (Engineering Science, EE major), Johns Hopkins University, 1958

BACKGROUND: Mr. Taylor has been with Vitro since 1960 and is currently engaged in the design of electronics for an underwater sonar acoustic television system. He has recently designed portions of a nuclear power plant safety equipment automatic control system and underwater target simulation equipment and participated in the design of geophone signal processor equipment, including a microelectronic dc-to-dc converter that enabled low-power consumption for the total unit. Previously, he was involved in the design and development of semiconductor circuitry in miniaturized repeaters for insertion in ship-to-torpedo wire communication links. Mr. Taylor has participated in the development of a color cathode-ray tube for a tactical display system and in the design of solid-state circuitry and techniques for magnetic tape recording; developed transistorized circuitry for wire termination equipments and ultrasonic converters used in a wire-acoustic link-wire communication link; taken part in the in-water testing and calibration of the electroacoustic transducers in the laboratory trim tank and at ORL's Black Moshannon facility and in the testing of the complete system at Key West, Florida; participated in the development of sonar and sonobuoy simulation equipment for detecting and locating hostile submarines; and previously was assigned to a program of design and development of an echo-ranging device used to make precise measurements of the size and shape of water supply wells and heat sinks under the Greenland ice cap at Camp Century.

Before joining Vitro, Mr. Taylor was with Bendix Radio for 2 years, where he worked on the voice communication link for Project Mercury and in the design and development of a transistorized UHF radio system for the Air Force.

APPENDIX I

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Encl: (1) List of DECLASSIFIED LRAPP Documents

1. In accordance with reference (a), a declassification review has been conducted on a number of classified LRAPP documents.

2. The LRAPP documents listed in enclosure (1) have been downgraded to UNCLASSIFIED and have been approved for public release. These documents should be remarked as follows:

   Classification changed to UNCLASSIFIED by authority of the Chief of Naval Operations (N772) letter N772A/6U875630, 20 January 2006.

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HLR167; CU-195-69-ONR-266-PHYS	Hardy, W. A.	PROJECT APTERYX: FINAL REPORT (U) (HUDSON LABORATORIES OPERATION 245)	Columbia Univ./ Hudson Labs	690301	NS; ND AD501319	C
MCR002	Unavailable	MEDITERRANEAN SEA ENVIRONMENTAL ATLAS FOR ITASS (U)	Maury Center for Ocean Science	691001	NS; ND AD502976	C
NUSCNL3018	Unavailable	TECHNICAL PLAN FOR IMPLANTMENT OF THE TEST BED ARRAY FOR THE LONG RANGE ACOUSTIC PROPAGATION PROGRAM (LRAPP) (U)	Naval Underwater Systems Center	700810	NS; ND	C
Project469 149429855R700	Balaban, M. M.	LRAPP TEST BED ARRAY CABLE FAILURE ANALYSIS (U)	TRW Systems Group	710730	AD0516710; NS; ND	C
BKDCN667	Bernard, P. G., et al.	TECHNICAL DIAGNOSTIC ANALYSIS OF LRAPP TEST BED PROGRAM FAILURE (U)	B-K Dynamics, Inc.	710802	AD0516656; NS; ND	C
NUSCPUB6002	Unavailable	IOMED EXPERIMENT. PRELIMINARY DATA REPORT (U)	Naval Underwater Systems Center	711206	NS; ND	C
ADL ED 15316; ADL-116-672	Unavailable	SQUARE DEAL EXERCISE PLAN (U)	Arthur D. Little, Inc.	720301	ND	C
ADLR4560372	Sullivan, D. L., et al.	PRELIMINARY ANALYSIS OF ACODAC MEASUREMENTS NEAR MADEIRA ON 13-16 OCTOBER 1971 (U)	Arthur D. Little, Inc.	720331	AD0595812; NS; ND	C
MCR07	Gaul, R. D., et al.	IOMEDEX SYNOPSIS ON ENVIRONMENTAL ACOUSTIC EXERCISE IN THE IONIAN BASIN OF THE MEDITERRANEAN SEA NOVEMBER 1971.	Maury Center for Ocean Science	720401	NS; ND	C
P1243	Unavailable	FINAL REPORT ACOUSTIC TEST ARRAY (U)	Raytheon Co.	720831	AD0522104; NS; ND	C
Unavailable	Unavailable	CHART-BATHYMETRIC-SQUARE DEAL EXERCISE (U)	Naval Oceanographic Office	730601	AU	C
TM SA23-C275-73	Wilcox, J. D.	A DESCRIPTION OF THE LRAPP ATLANTIC TEST BED ARRAY FOR MOTION PREDICTION STUDIES (U)	Naval Underwater Systems Center	731212	ND	C
Unavailable	Unavailable	CHURCH ANCHOR AMBIENT NOISE REPORT (U)	Texas Instruments, Inc.	740501	AU	C
Unavailable	Hoffman, J., et al.	CHURCH ANCHOR CW PROPAGATION LOSS AND SIGNAL EXCESS REPORT(U)	Texas Instruments, Inc.	740701	AU; ND	C
MCR104	Unavailable	MEDITERRANEAN ENVIRONMENTAL ACOUSTIC SUMMARY (U)	Maury Center for Ocean Science	740701	NS; ND	C
OSTP-39	Romain, N. E.	OSTP-39 NER: ANALYSIS OF DATA FROM A FIELD TRIAL OF THE LAMBDA ARRAY (U)	Westinghouse Electric Corp. and Bell Laboratories	740930	ND	C
MC-103	Unavailable	MEDITERRANEAN ENVIRONMENTAL ACOUSTIC DATA CATALOG (U)	Office of Naval Research	750501	ND	C
Unavailable	Unavailable	SQUARE DEAL SUS TRANSMISSION LOSS (U)	Arthur D. Little, Inc.	750725	AU	C

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